National Aeronautics and Space Administration

MARS EXPLORATION PROGRAM

Update to Planetary Sciences Advisory Committee

February 22, 2018

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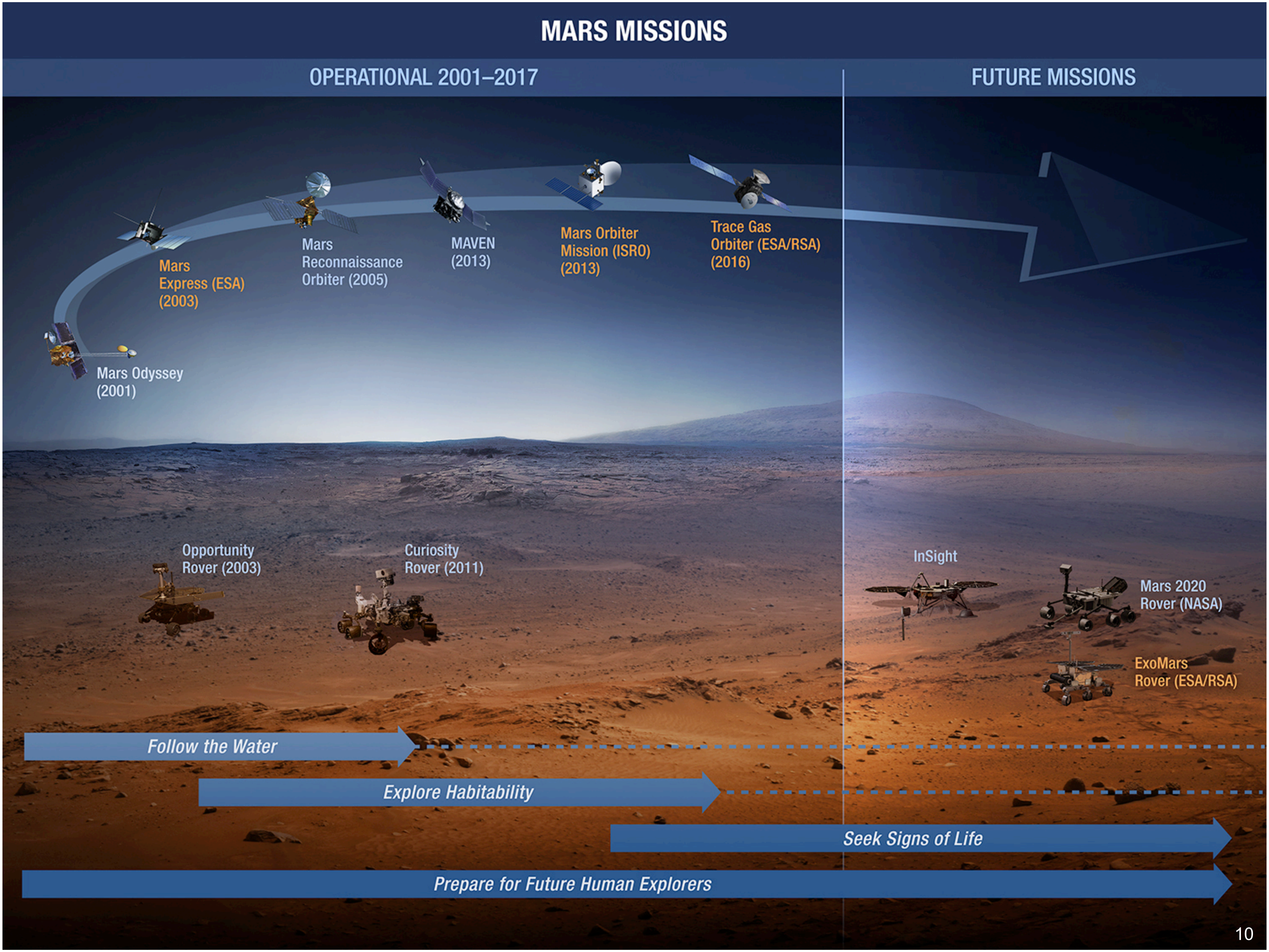
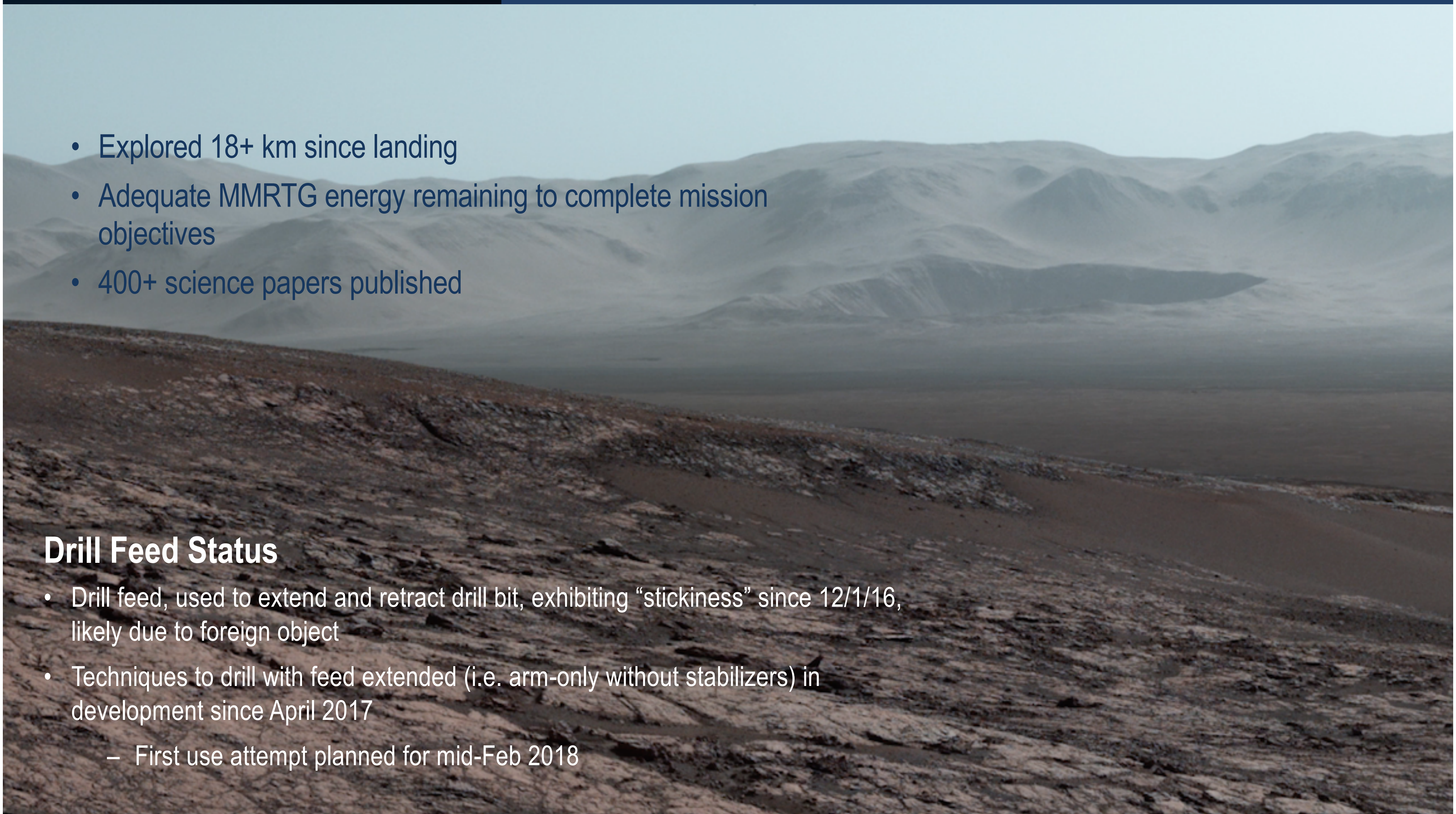
MARS EXPLORATION PROGRAM – SUMMARY

- Decadal Survey science goals
  - Determine if life ever arose on Mars
  - Understand the processes and history of climate
  - Determine the evolution of the surface and interior
- Progress report
  - Making breakthroughs in Mars science
  - Gaining knowledge in preparation of future Mars exploration
  - Current missions are healthy and performing well
  - Technology investments are addressing pivotal issues for future Mars exploration architectures
- Our future architectures should adapt to evolving interests in Mars exploration
  - Existing program capabilities
  - Multiple international interests
  - Multiple commercial interests
- Investigating new, leaner Mars architectures to respond to global changes in Mars exploration


MARS MISSIONS
OPERATIONAL 2001–2017
FUTURE MISSIONS
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
Opportunity Rover (2003)
Curiosity Rover (2011)
InSight
Mars 2020 Rover (NASA)
ExoMars Rover (ESA/RSA)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

Ongoing Program Highlights

MSL Exploration of GALE Crater



- Explored 18+ km since landing
- Adequate MMRTG energy remaining to complete mission objectives
- 400+ science papers published

Drill Feed Status

- Drill feed, used to extend and retract drill bit, exhibiting “stickiness” since 12/1/16, likely due to foreign object
- Techniques to drill with feed extended (i.e. arm-only without stabilizers) in development since April 2017
  - First use attempt planned for mid-Feb 2018

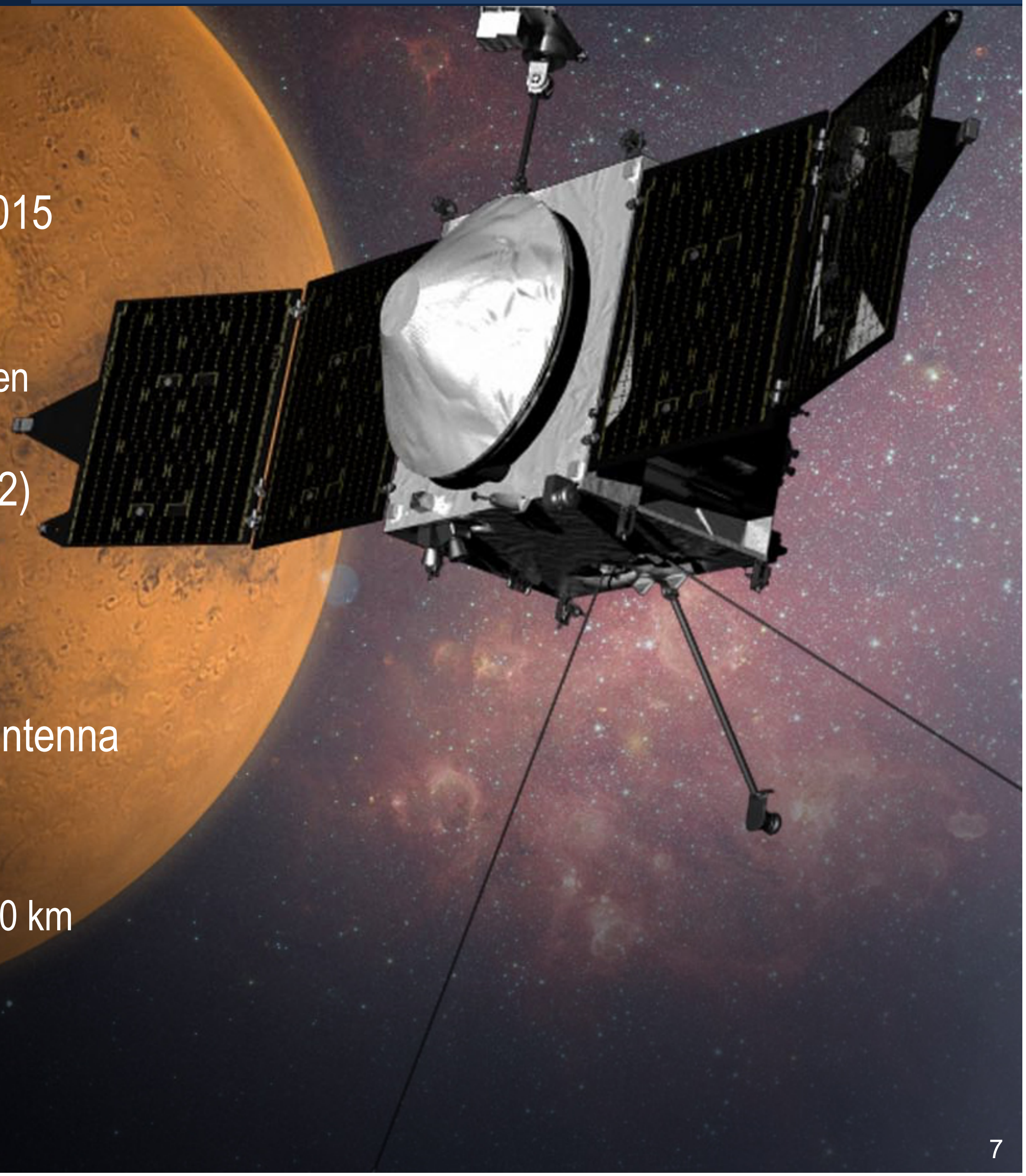
Curiosity at Martian Scenic Overlook

MRO – MISSION STATUS

- Launched in August 2005, achieved MOI March 2006
- Science Orbit since November 2006
  - Low Altitude = 250 km x 320 km
  - Inclination = 93.3 deg, Sun-Sync at 3:00 pm
  - Instruments nominal
- Success with both scientific and programmatic objectives (relay, reconnaissance, critical event coverage)
  - Over 309 Tb of science data returned
  - Completed imaging of ~95% of requested Mars 2020 landing sites
  - UHF Relay for PHX (past), MER, & MSL
  - Future relay for InSight, Mars 2020, & ESA ExoMars
- Healthy spacecraft with large fuel reserves (> 20 years)
  - Single string telecomm since 2006
  - All-stellar capability developed to preserve IMU life

MAVEN – MISSION STATUS

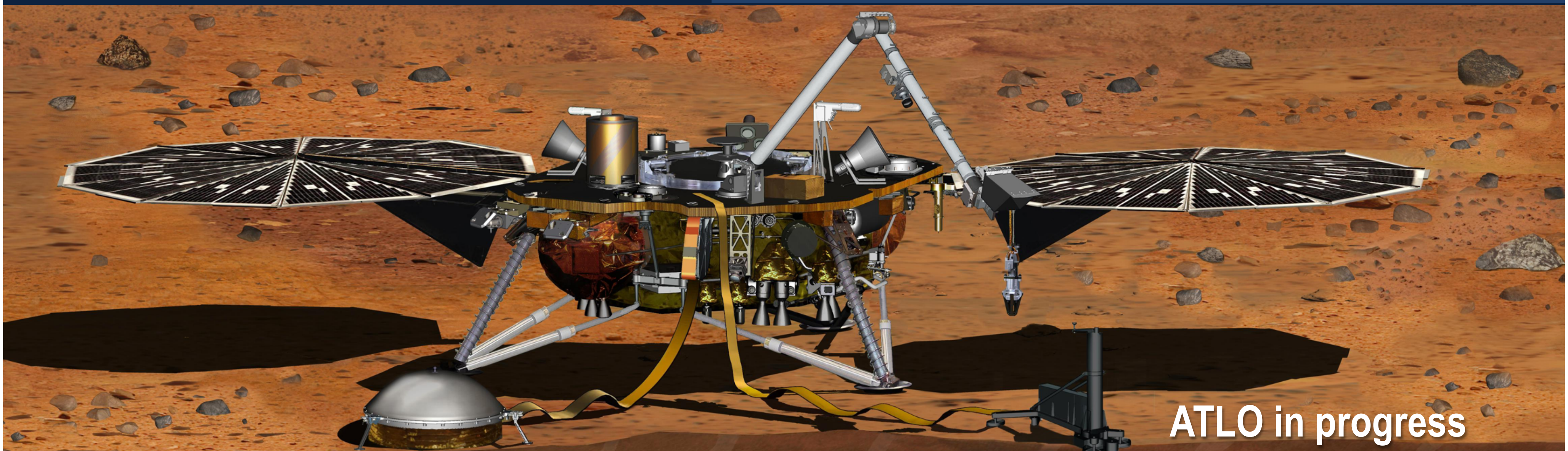
- Launched November 2013, achieved MOI September 2014
- Completed primary mission in November 2015
  - Met all mission success criteria and Level-1 requirements
  - Provided strong evidence for solar wind driven atmospheric loss history
- Currently in second extended mission (EM-2) through September 2018
- Spacecraft is in excellent health, with all instruments operating
- Carries Electra UHF transceiver and UHF antenna
- Plan to reduce apoapsis for improved relay performance in 2019
  - Apoapsis change from 6200 km to 4000/4500 km
  - Incorporating approaches to preserve fuel



TRACE GAS ORBITER – MISSION STATUS

- Launched March 14, 2016, achieved MOI October 19, 2016
- Aerobraking in process; plan to reach final 400-km orbit by ~ March 2018
- Primary mission science/relay operations planned through Dec 2022
  - Planned fuel reserves for extended mission operations
- ESA’s ExoMars/Trace Gas Orbiter carries two NASA -provided Electra UHF relay payloads
  - Will provide relay services to both NASA and ESA landers/rovers
    - Successful post-MOI Relay Checkout w/ MSL, MER: Nov 22, 2016

INSIGHT - MISSION STATUS



ATLO in progress

Spacecraft Full Functional completed, SEIS and other payload elements installed on Lander on August, 3 2017

- Contributed science instruments
  - CNES: SEIS (Seismometer)
  - DLR (Heat flow & Physical Properties Package)
- Proceeding towards launch – May 5, 2018
  - PSR complete – Feb 1, 2018
  - Ship to VAFB – Feb 28, 2018
- Landing November 26, 2018

M2020 ROVER

A. GEOLOGIC EXPLORATION
B. HABITABILITY & BIOSIGNATURES
C. PREPARE A RETURNABLE CACHE
D. PREPARE FOR HUMAN EXPLORATION

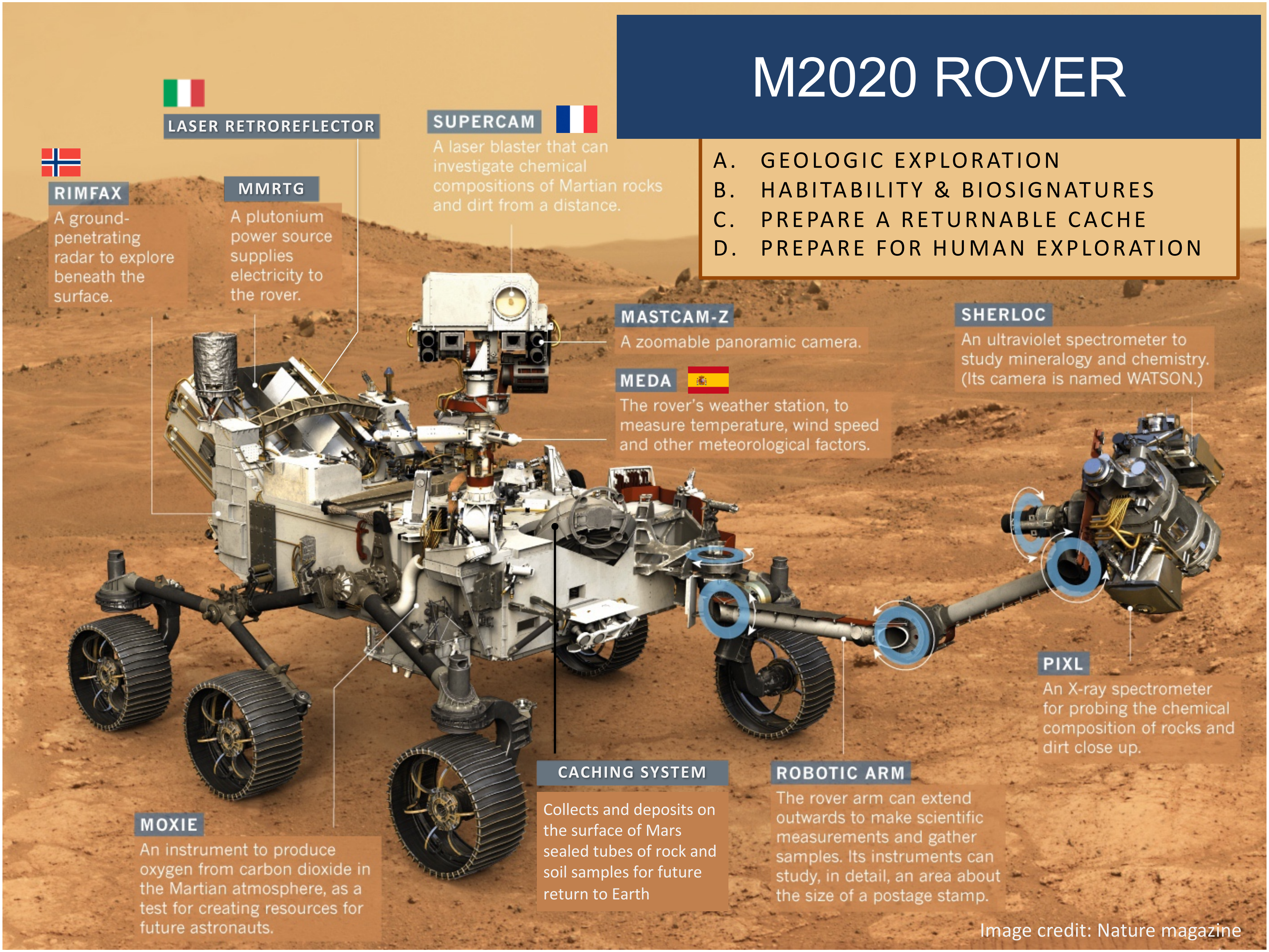
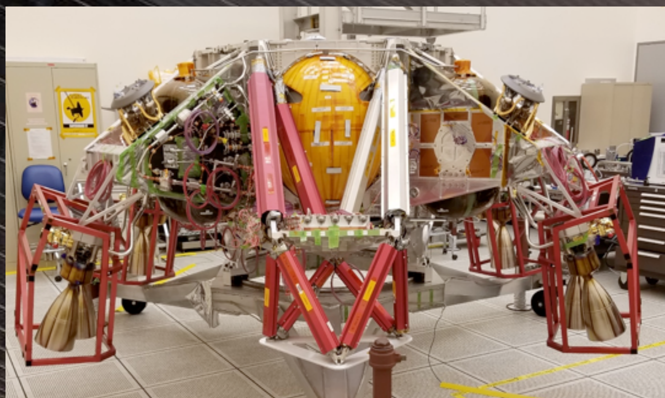


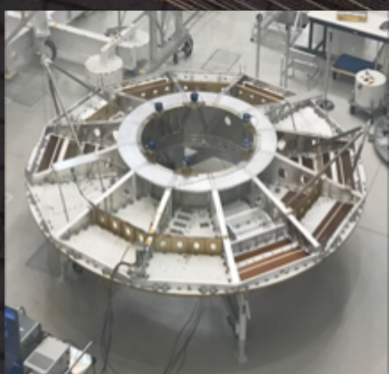
Image credit: Nature magazine

1 Year post-CDR: Development Well Along

Ready to proceed to System Integration Review (SIR) in February 2018



Flight Descent Stage



Flight Cruise Stage

Parachute Testing

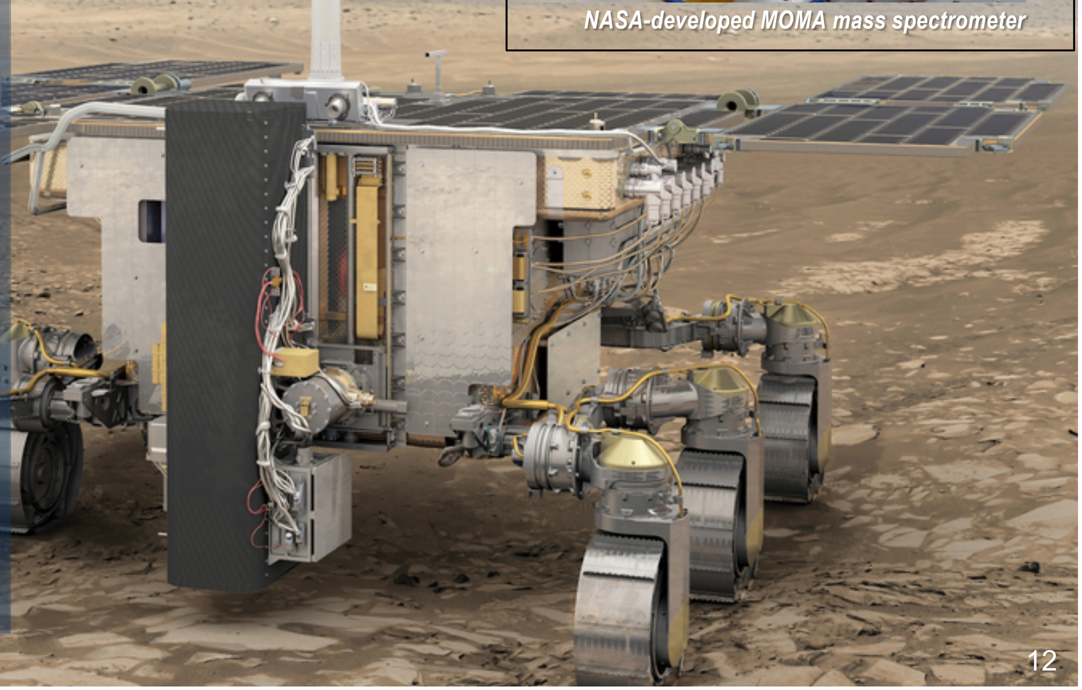
Sensors & Electronics

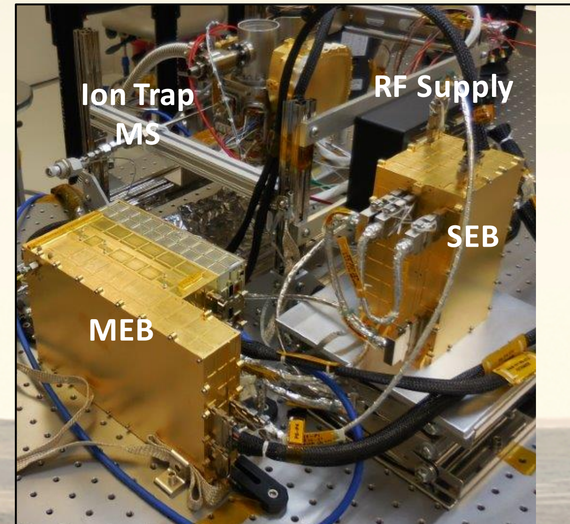
Flight Aeroshell

NASA CONTRIBUTION TO ESA EXOMARS

Mars Organic Molecule Analyzer (MOMA)

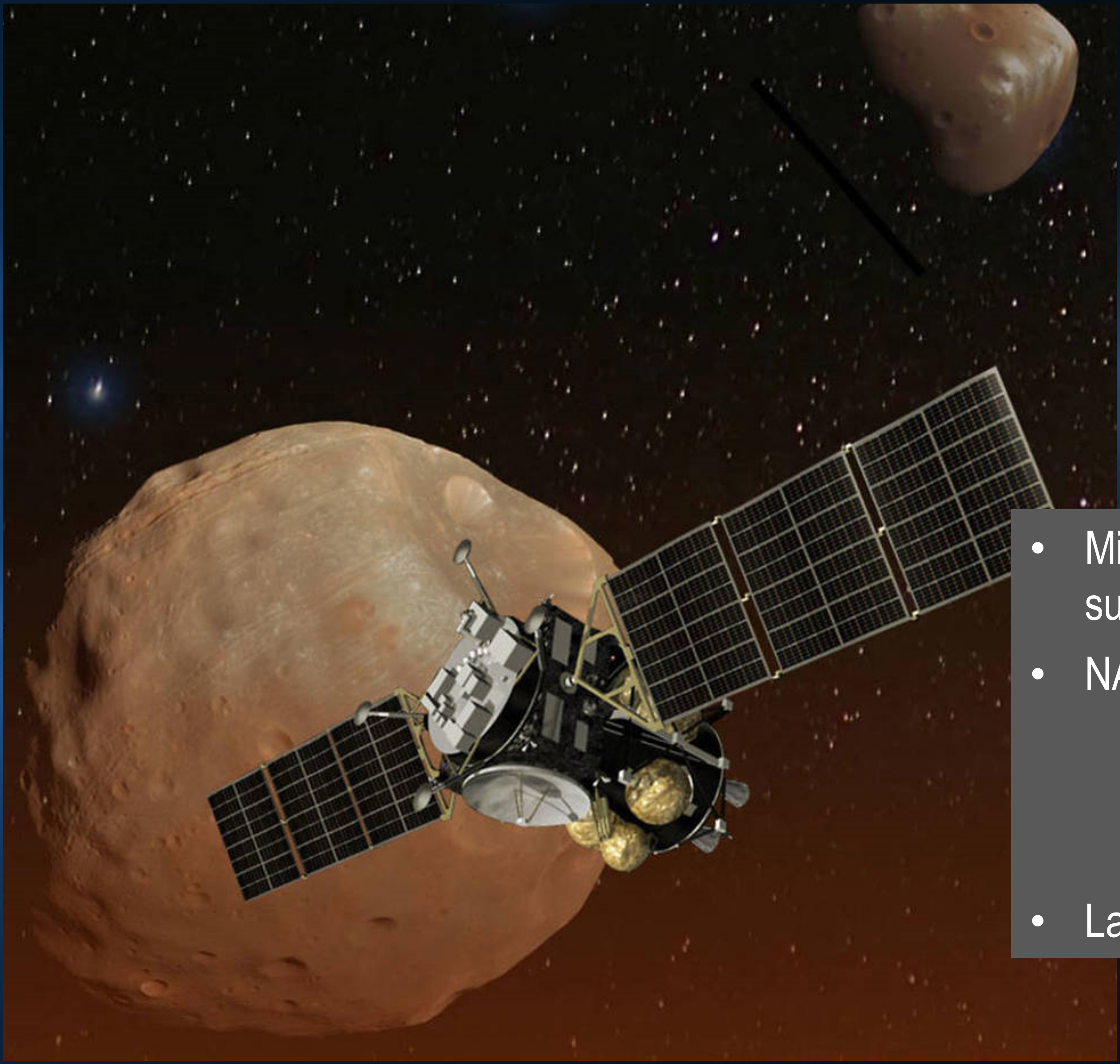
- Central organic bio-signature analysis experiment on ExoMars Rover
  - Gas chromatography and laser desorption sampling to characterize complex organics
- Led by Max Planck Institute for Solar System Research (MPS)
  - NASA/GSFC providing ion trap mass spectrometer and electronics
  - CNES providing GC
- Rover's 2-meter sampling drill provides unique samples, well-protected from cosmic radiation
- Instrument in environmental test campaign
- Launch July 2020; EDL March 2021





NASA-developed MOMA mass spectrometer

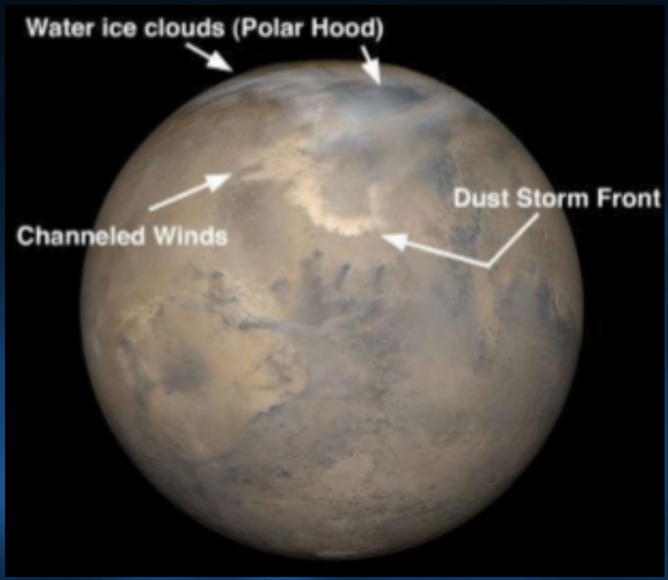
JAXA Mars Moons eXploration - MMX

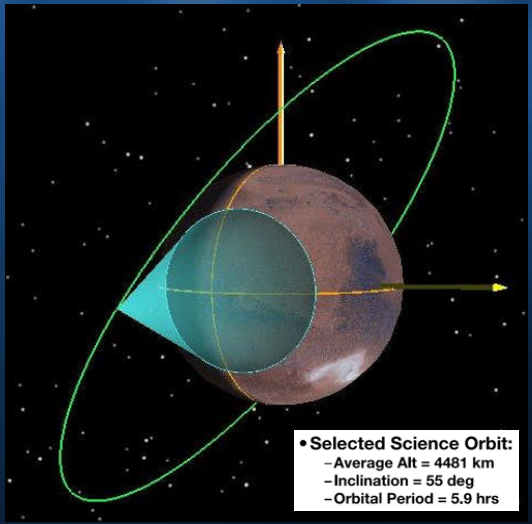


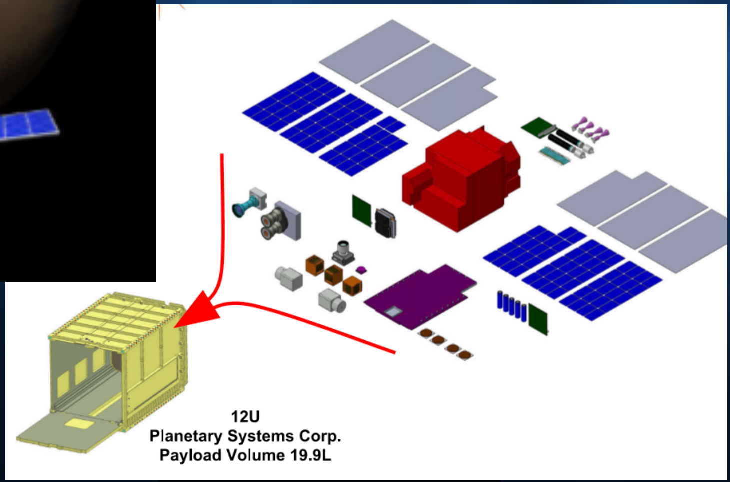
- Mission to study Mars moons & return surface samples from Phobos
- NASA providing:
  - MEGANE (JHUAPL) neutron and gamma-ray spectrograph
  - Pneumatic sampler (HBR)
- Launch 2024

Mars Micro Orbiter (MMO)

- **Highly Ranked SIMPLEx-2014:** proposal selected for risk reduction funding. After first risk reduction study was completed, a second grant was issued for technical development
  - PDR – March 28-30, 2018
- **PI: Michael Malin, MSSS**
- **Science Objective:** Global environmental monitoring of Mars



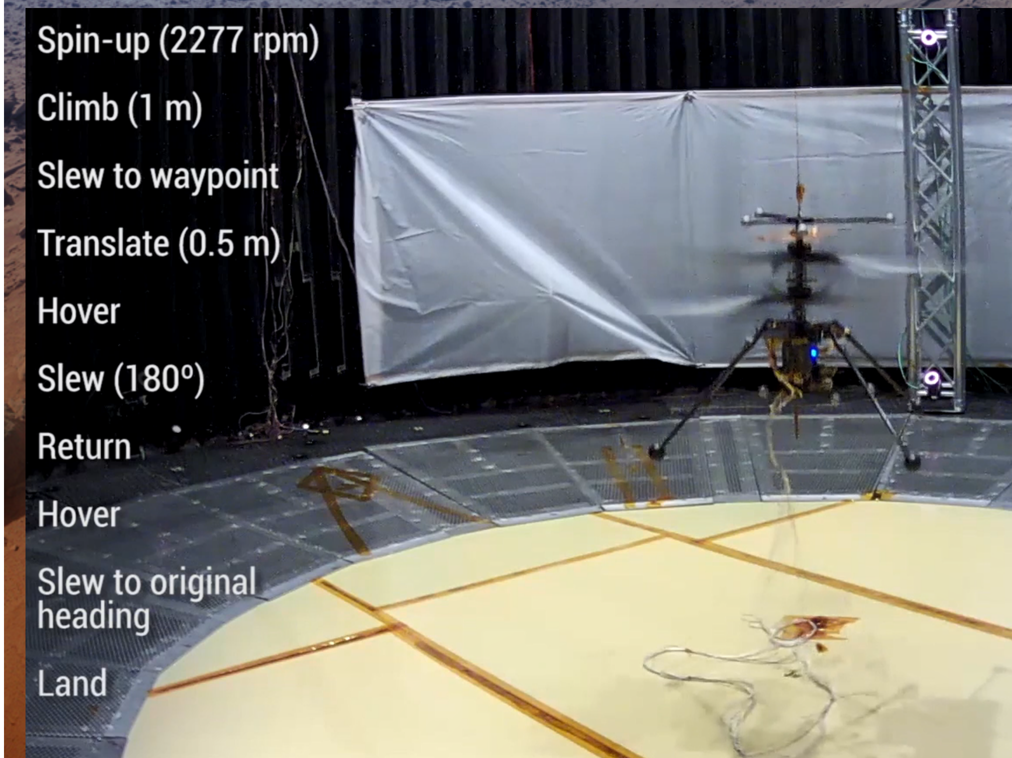




MARS HELICOPTER - TECHNOLOGY DEVELOPMENT

Objective - Explore utility of Mars aerial mobility

- Regional-scale high-resolution reconnaissance to facilitate surface operations of future robotic missions
- Access to extreme terrains, Rover scouting
- Mass < 2 kg, solar powered,300 m range on one charge, autonomous, dual cameras

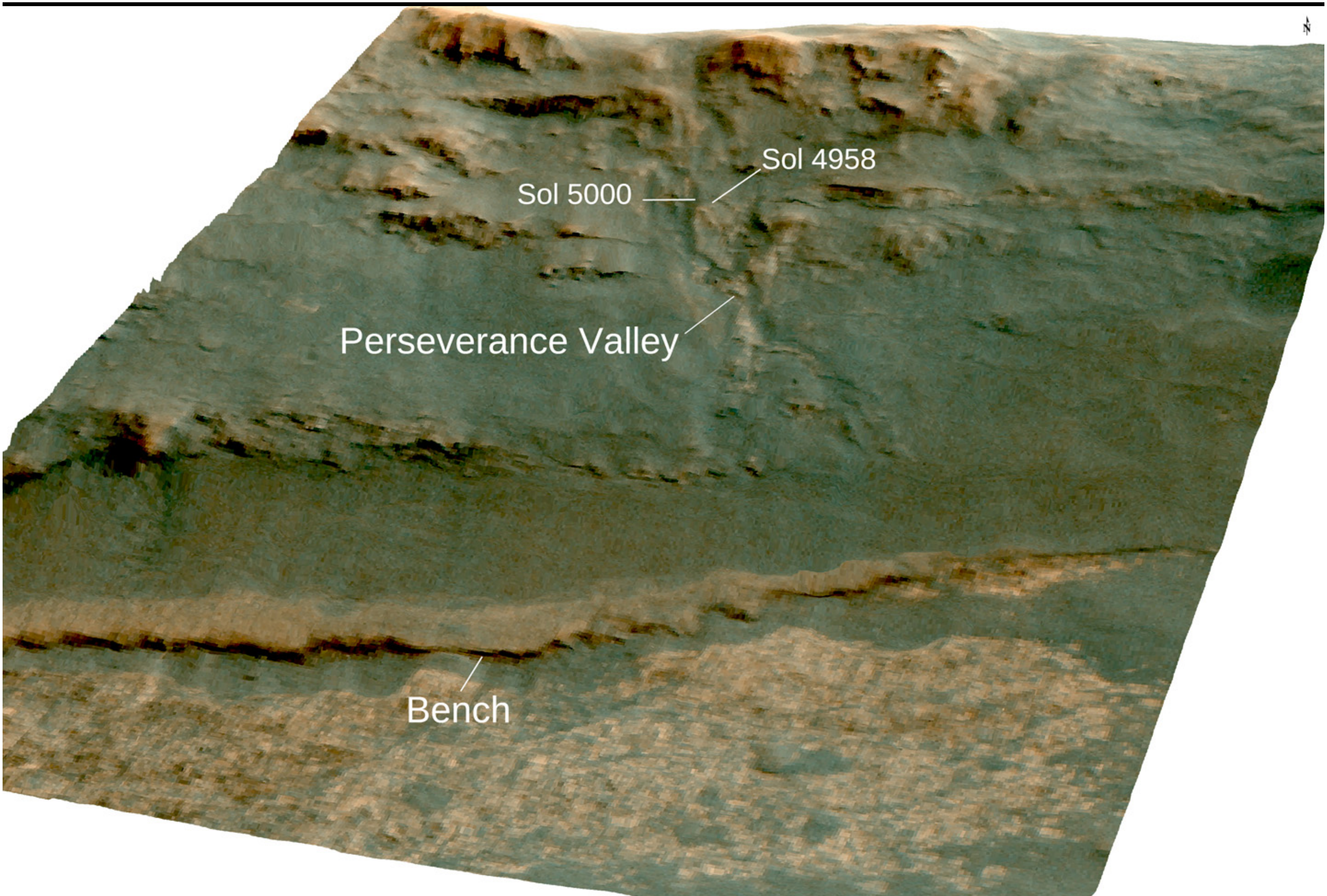


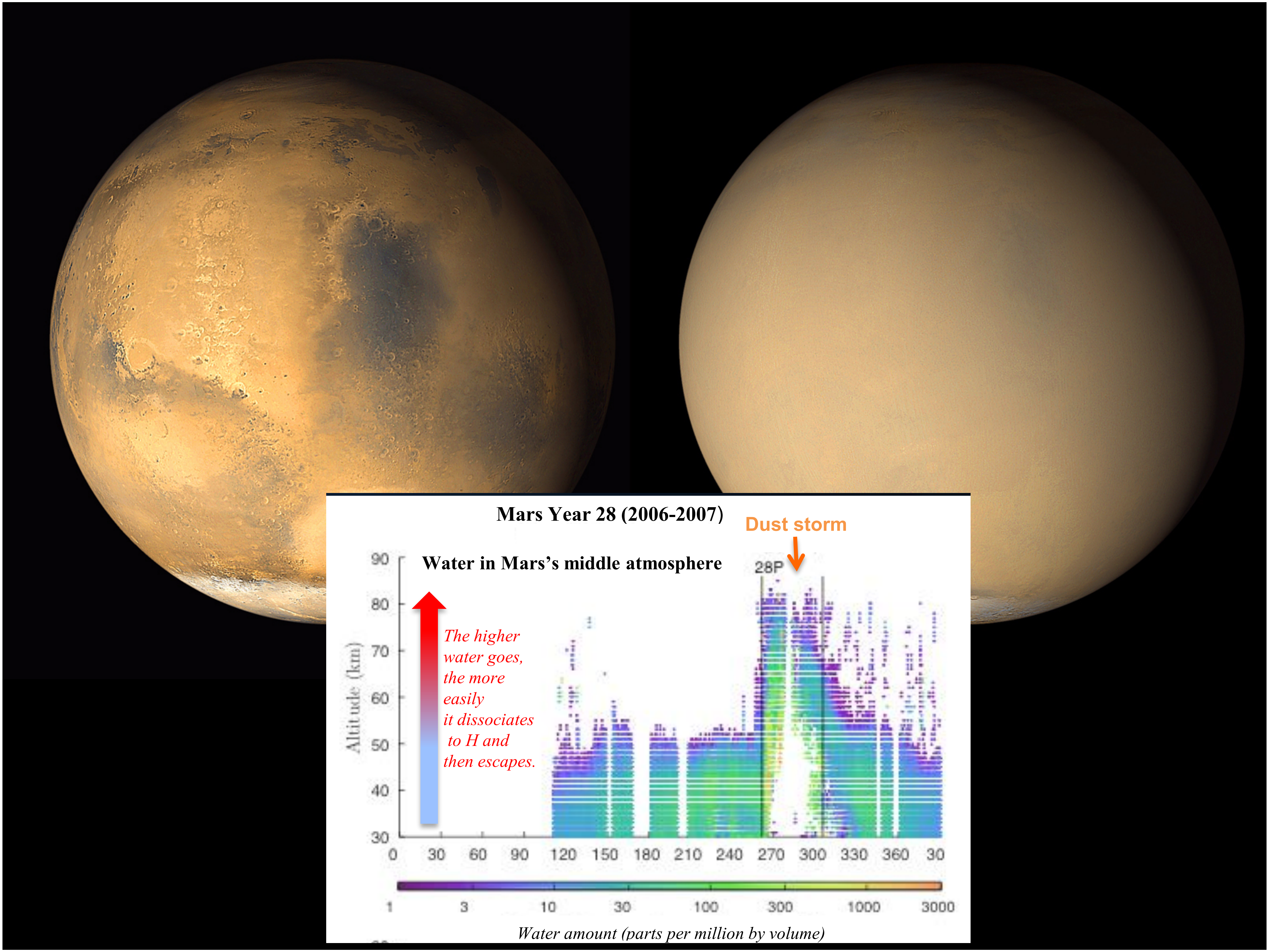
Full-scale free flight testing in JPL Space Simulator

Technology Maturation Progress

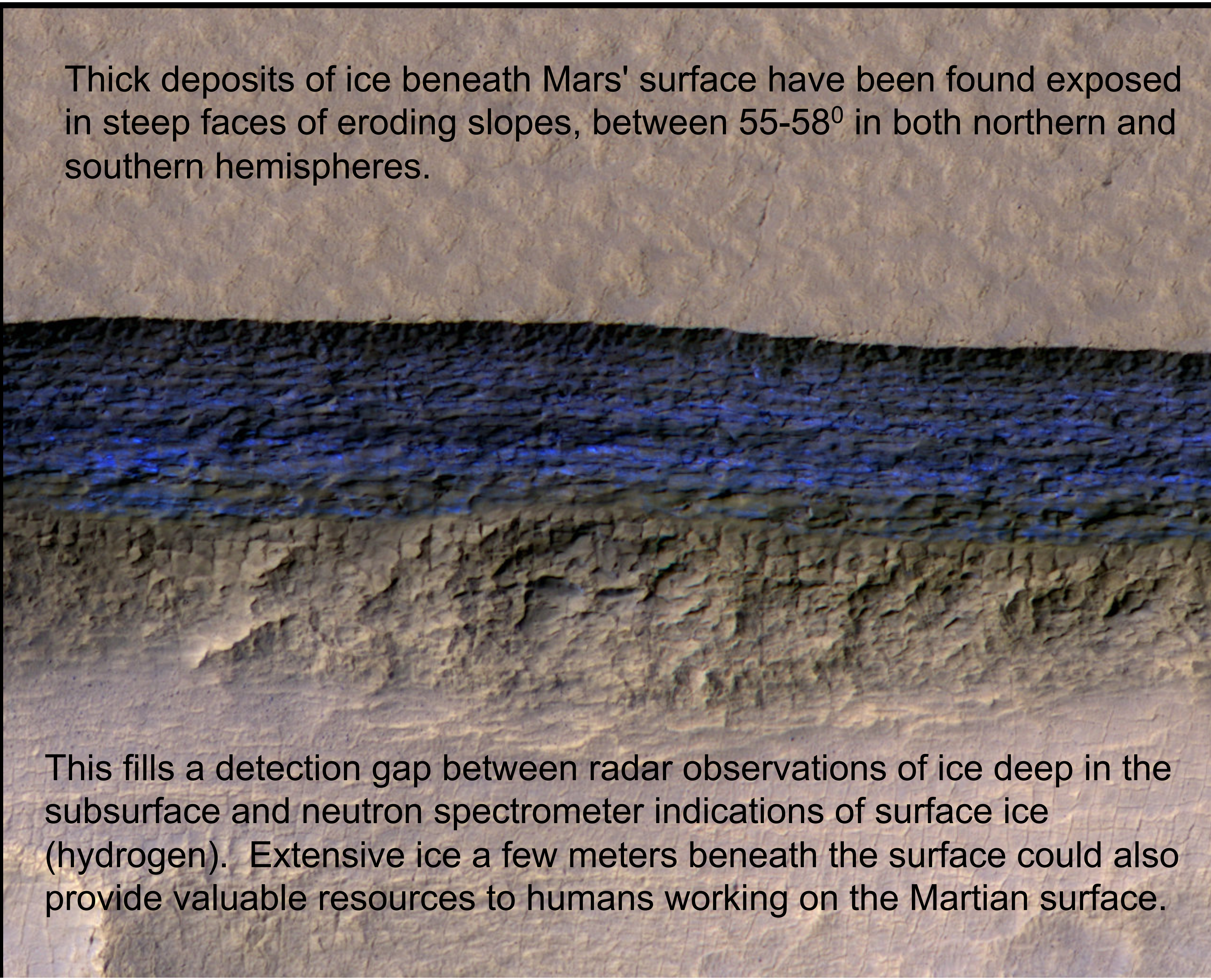
- ✓ Controlled-flight feasibility demonstration – June 2016
- ✓ Engineering Model build & test complete – Feb 2018
  - ✓ 86 mins accumulated flight time in Mars environment
- ○ Decision on flight opportunity pending

Science Highlights


Sol 4958
Sol 5000
Perseverance Valley
Bench

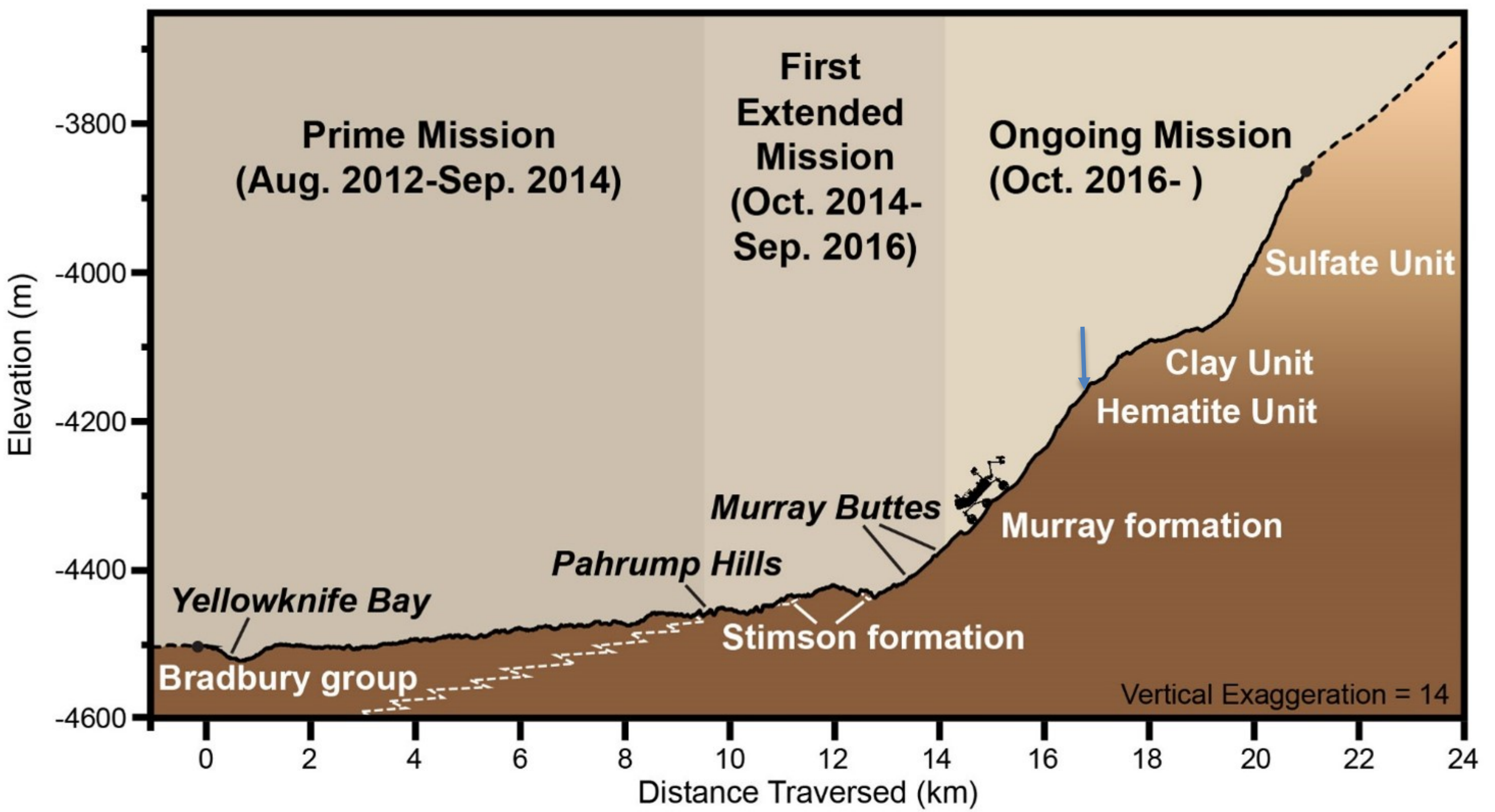

Mars Year 28 (2006-2007)
Dust storm
Water in Mars's middle atmosphere
28P
Altitude (km)
90
80
70
60
50
40
30
The higher water goes, the more easily it dissociates to H and then escapes.
0 30 60 90 120 150 180 210 240 270 300 330 360 30
1 3 10 30 100 300 1000 3000
Water amount (parts per million by volume)

Thick deposits of ice beneath Mars' surface have been found exposed in steep faces of eroding slopes, between $55\text{-}58^0$ in both northern and southern hemispheres.



This fills a detection gap between radar observations of ice deep in the subsurface and neutron spectrometer indications of surface ice (hydrogen). Extensive ice a few meters beneath the surface could also provide valuable resources to humans working on the Martian surface.

Curiosity Heading Up Mt. Sharp



From SAM Evolved Gas (EGA) Experiment → noble gases, organic & inorganic compounds & many isotopes

Evolved gases

H_2O – from hydrated minerals, adsorbed water, or clays

SO_2 & H_2S - from sulfates & sulfides

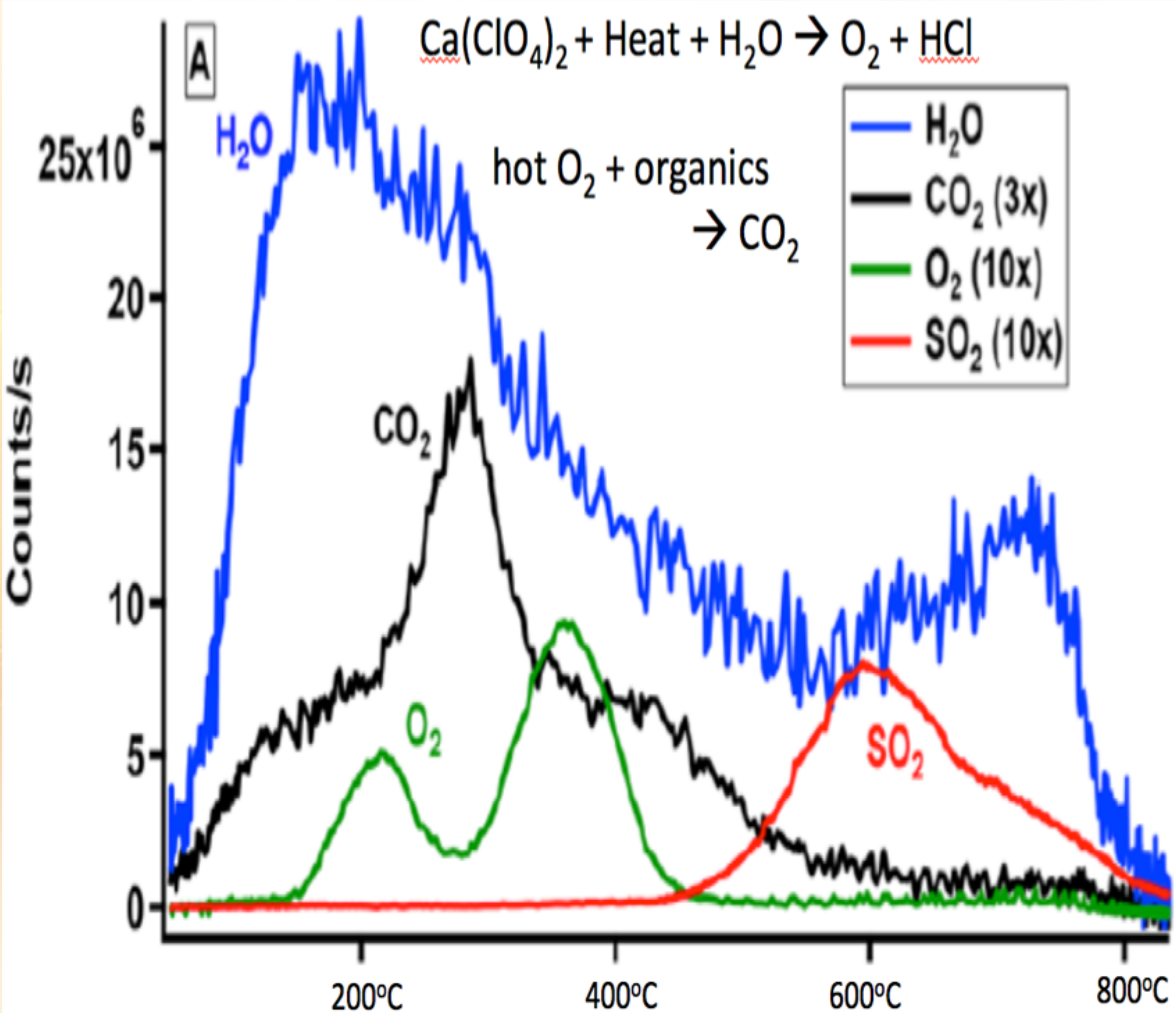
O_2 & HCl - from perchlorates or oxychlorine compounds

NO - from nitrates

Organics (incl. CH_4)

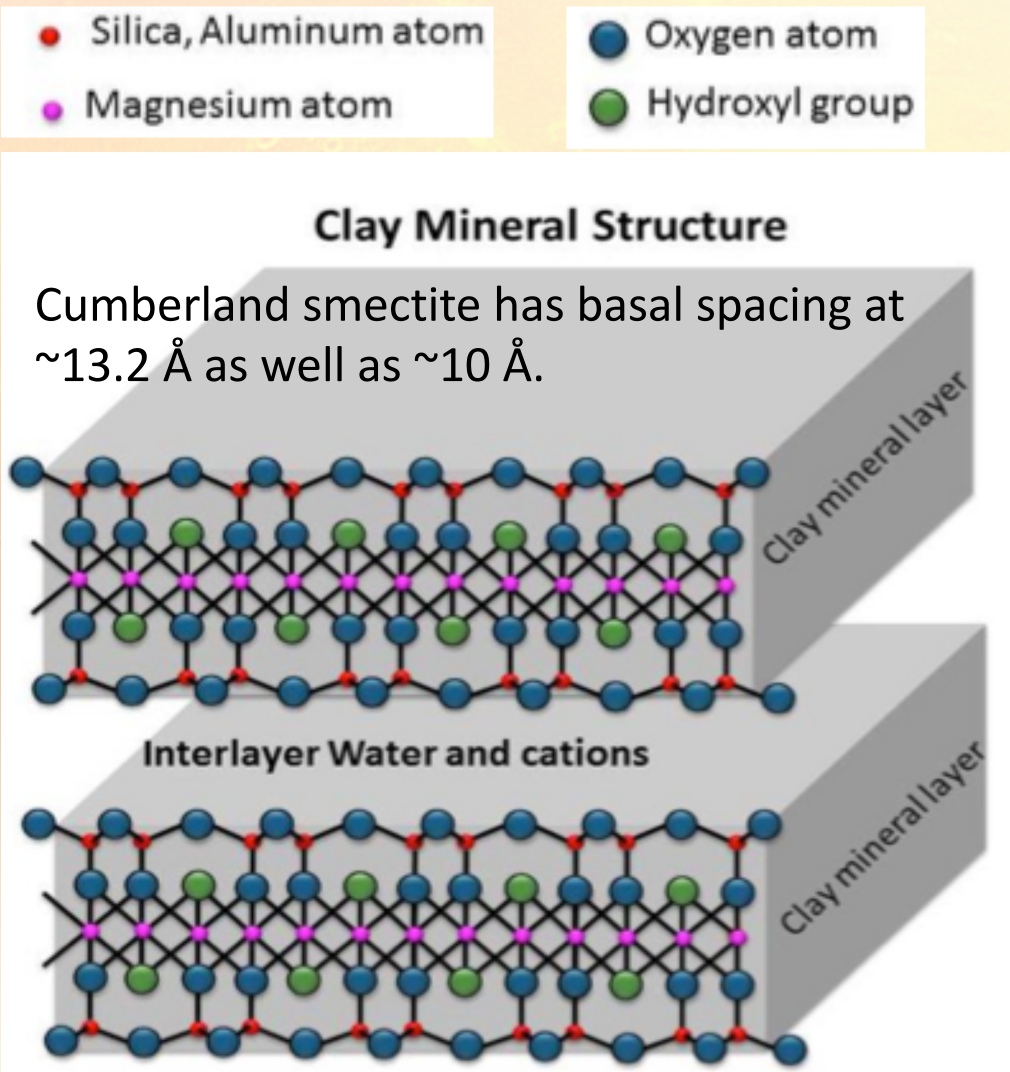
He, Ar, Ne – rock formation & exposure age determinations

CO_2 & CO – from carbonates or combusted organics



Yellowknife Bay smectite clays were early targets for a search for organics and for examining preservation environments

Detrital basaltic minerals, Ca-sulfates, Fe oxide/hydroxides, Fe-sulfides, amorphous material, and trioctahedral smectites.



Cumberland smectite has basal spacing at ~13.2 Å as well as ~10 Å.

- Spallogenic noble gas products ^{3}He, ^{21}Ne, and ^{36}Ar extracted from the Cumberland rock
  → a cosmic radiation exposure age of 80 million years

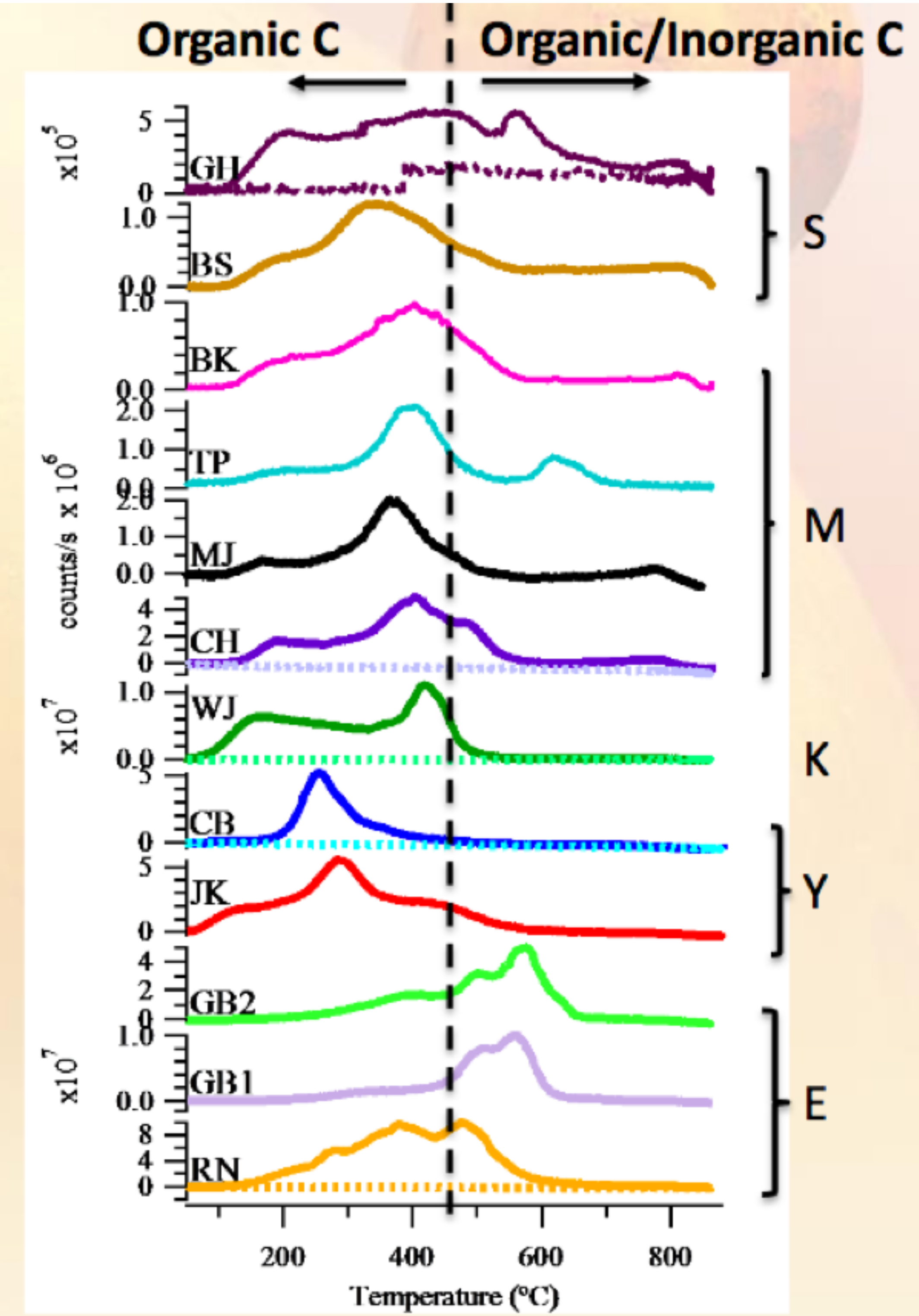
- ^{40}Ar extracted from the Cumberland rock **plus APXS measurement of K**
  → rock formation age of 4.2 billion years

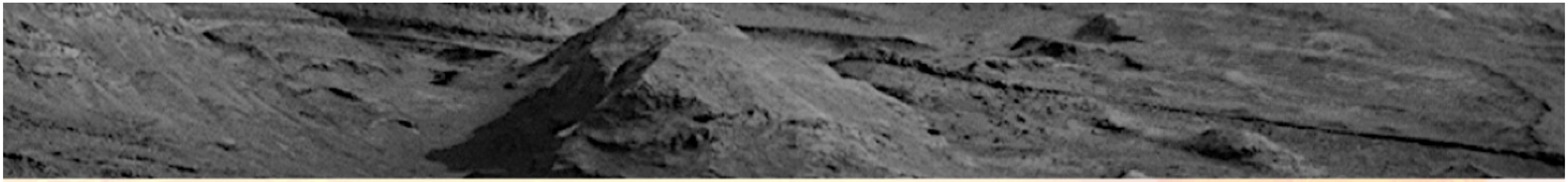
- HDO and H_2O released from hydroxyl groups
  →D/H ratio of half that of the present atmosphere and suggest at least 10's of meters of water lost to space

- Interlayer of clay provided a preservation environment for organics
  → multiple chlorinated species detected

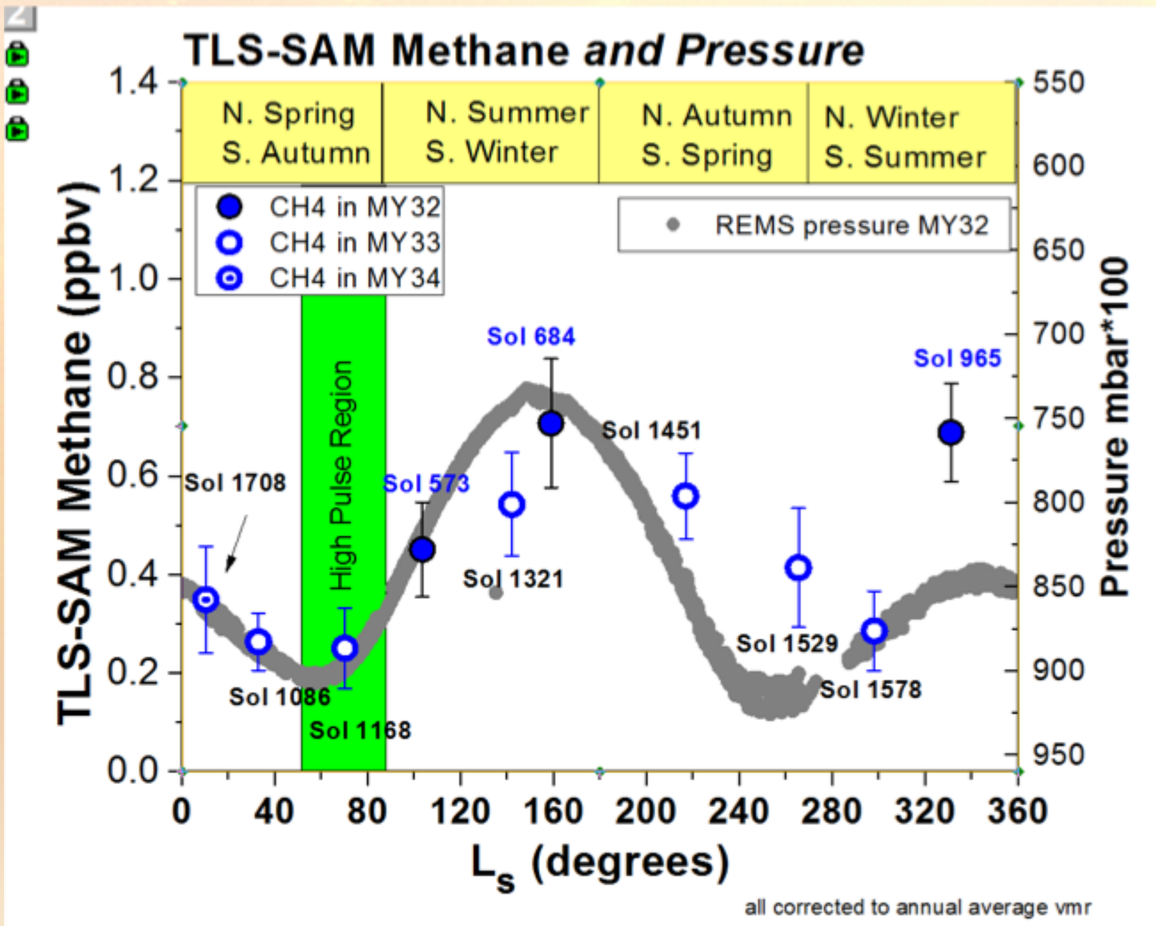
Carbon from organic and inorganic sources

- 100 to 2400 µg C/g
- Much of the CO_2 consistent with combusted organic carbon
- Some consistent with carbonate
- High T CO_2 and CO from magmatic C (Steele et al. 2002)
- Direct evidence for organic-C in both EGA and GCMS data
- Sufficient organic-C to be consistent with ancient heterotrophic biosphere in Gale → 10^3 to 10^5 cells/g sediment
- Seafloor sediments in South Pacific Gyre 600-2000 µg organic-C/g sediment with $6x10^3$ – $5x10^5$ cells/g sediment (D'Hondt et al 2010 & 2015)
- 60 µg C/g (60 ppm C) predicted from meteorite flux (Steininger et al., 2012)





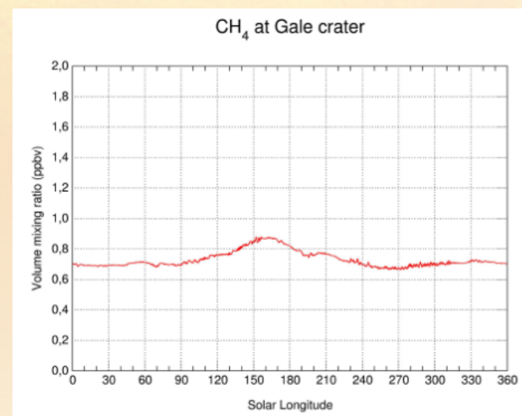
Mars Methane Background shows Strong Seasonal Dependence



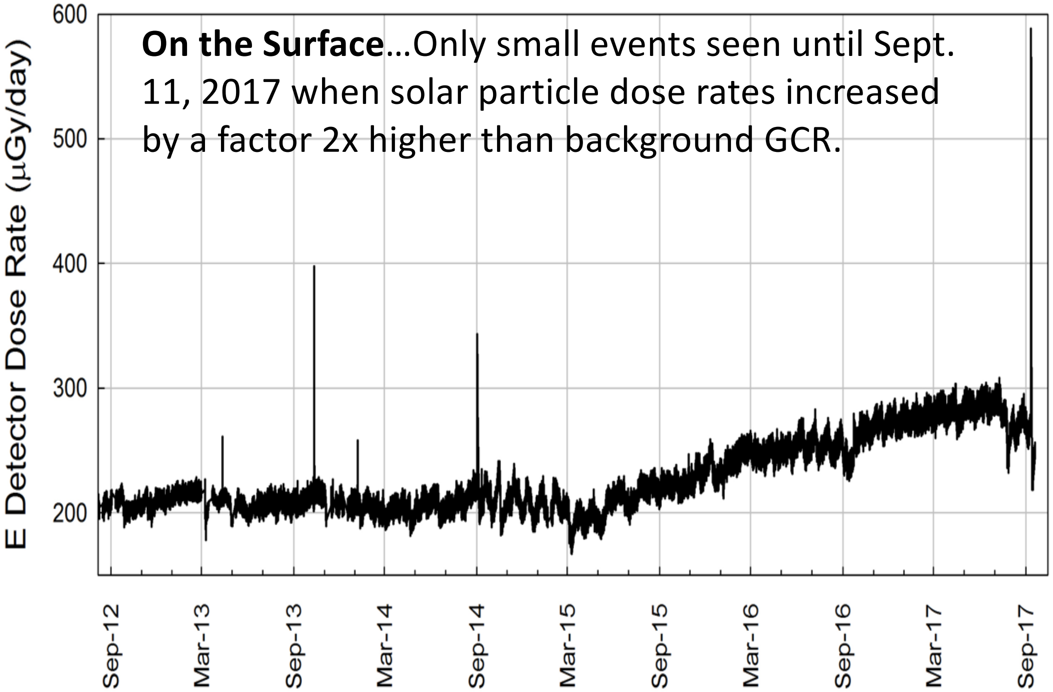
- **Low background levels of 0.41 ±0.10 (2sem) ppbv are ~6 times lower (!) than model predictions** (Schuerger et al.*) accounting for planetary infall (dust, meteoritic, cometary) production of methane.

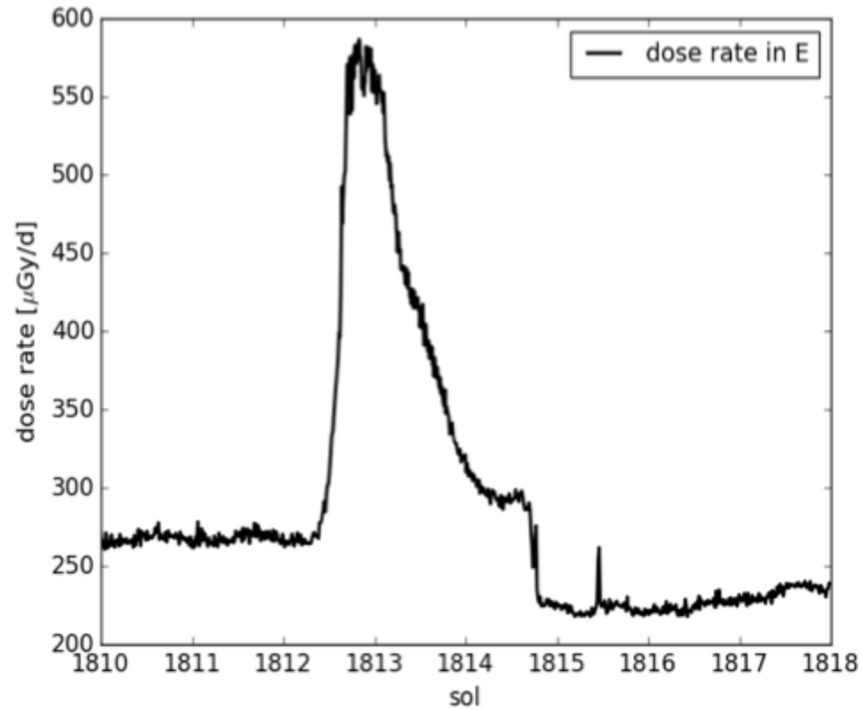
  *Model: 10 wt% C material, 20% conversion.

- **Lefèvre-Forget model 2016 predicts only ~20% seasonal change**



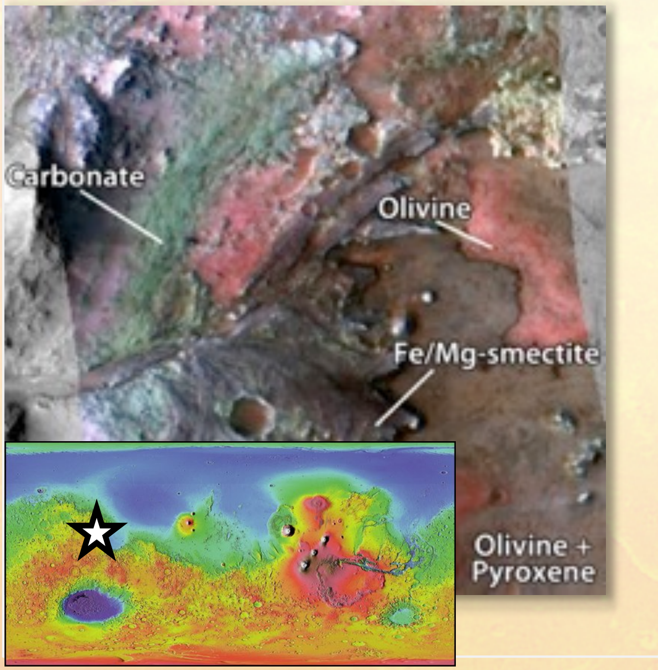
Although approaching Solar Minimum, MSL/RAD observed, in Sept. 2017, the largest solar particle event seen on the surface of Mars since landing





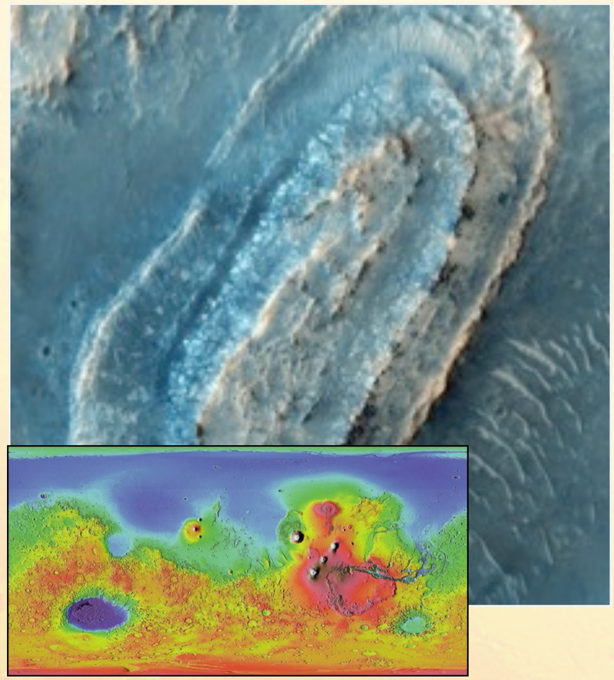
- Together with MAVEN in Mars orbit, MSL RAD is helping to understand the impact of Solar Storms and Solar Particle events on the Mars surface.
  - Characterization of these events on the surface help us understand what to expect and better prepare for future human exploration of Mars.

Final Mars 2020 Candidate Landing Sites



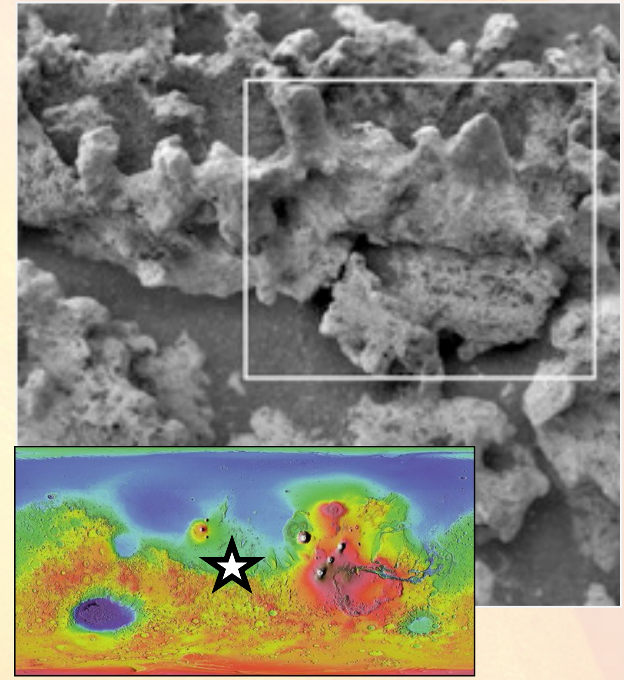
JEZERO

- Deltaic/lacustrine deposition with Hesperian lava flow and hydrous alteration
- Evidence for hydrous minerals from CRISM, *including carbonates*



NE SYRTIS

- Extremely ancient igneous, hydrothermal, and sedimentary environments
- High mineralogic diversity with phyllosilicates, sulfates, carbonates, olivine
- Serpentinization and subsurface habitability?



COLUMBIA HILLS

- Carbonate, sulfate, and silica-rich outcrops of possible hydrothermal origin and Hesperian lava flow
- Potential biosignatures identified
- Previously explored by MER

Future Program Highlights

FY 2019 Budget

Program Highlights

Planetary Science

Exploration program supports commercial partnerships and innovative approaches to achieving human & science exploration goals

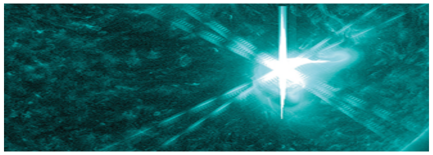
- New Planetary Defense program includes DART development
- Europa Clipper launch as early as FY25
- Plan a potential Mars Sample Return mission

Astrophysics

launch

- Given its significant cost within a proposed lower budget for Astrophysics and competing priorities within NASA, WFIRST terminated with remaining WFIRST funding redirected towards competed astrophysics missions and research

Heliophysics



strengthen cross-agency collaboration on Research-to-Operations/Operations-to-Research

- Provides for a balanced Heliophysics portfolio, including enhanced emphasis on small missions, technology development and expanded opportunities for R&A

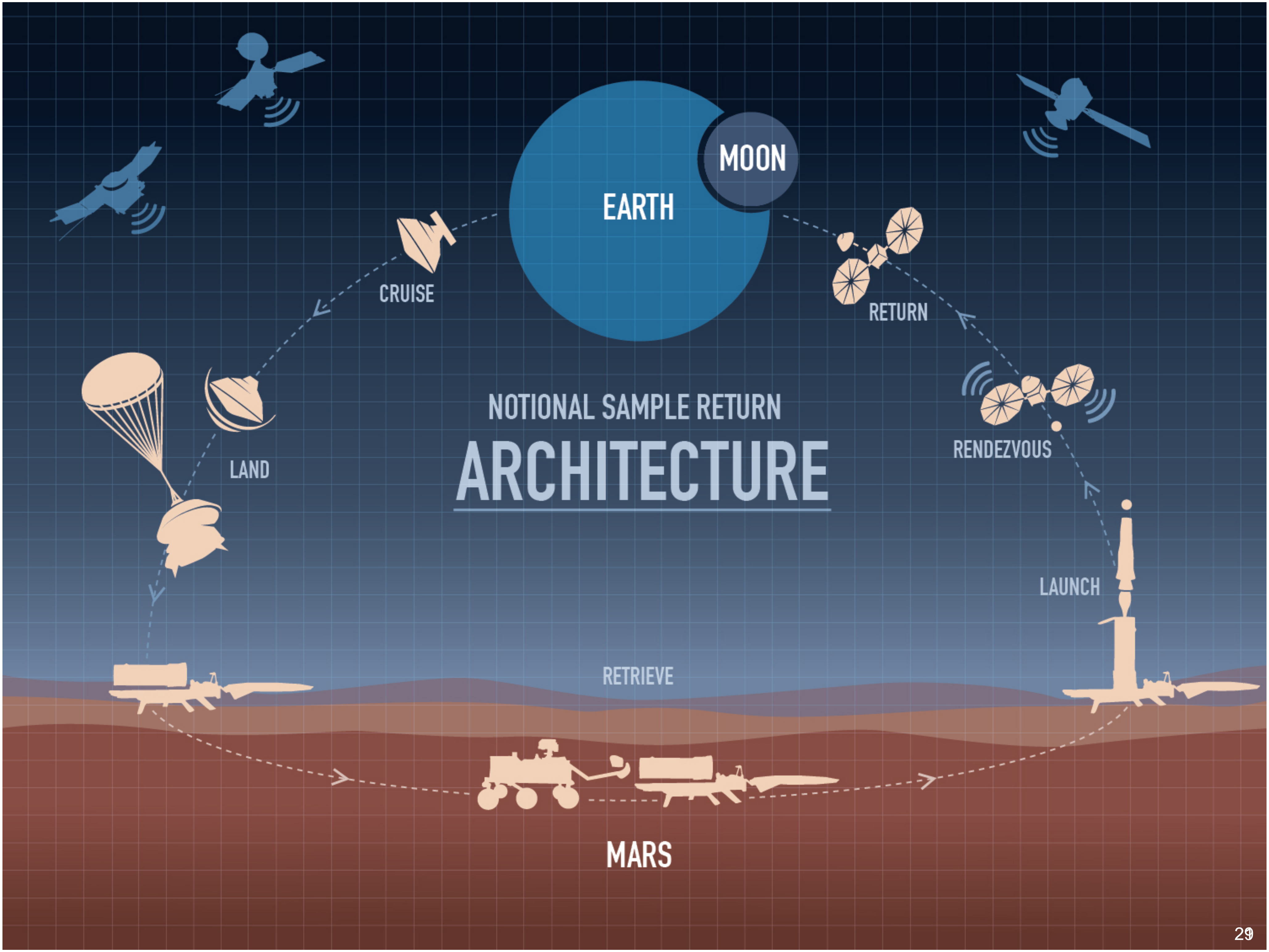
Earth Science

- Maintains regular cadence of Venture Class missions and instruments solicitations
- Healthy research and applied science programs, and SmallSat/CubeSat investments

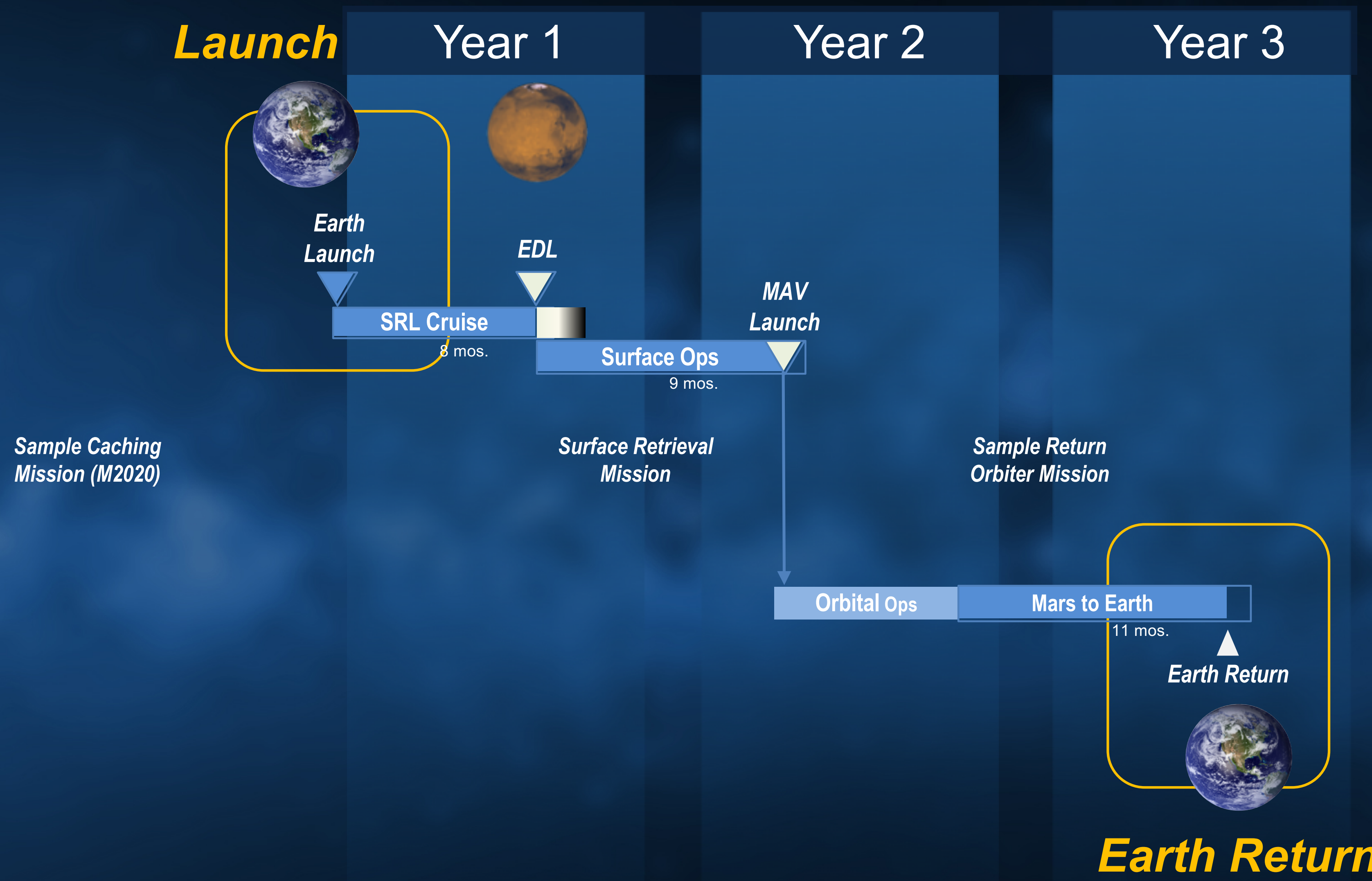
➢ Continue all ongoing **MEP Missions**

➢ Continue **M2020 Development**

➢ Plan a potential **Mars Sample Return** mission, a decadal survey priority, leveraging international and commercial partnerships


MOON
EARTH
CRUISE
RETURN
NOTIONAL SAMPLE RETURN
ARCHITECTURE
LAND
RENDEZVOUS
LAUNCH
RETRIEVE
MARS

NOTIONAL MSR TIMELINE

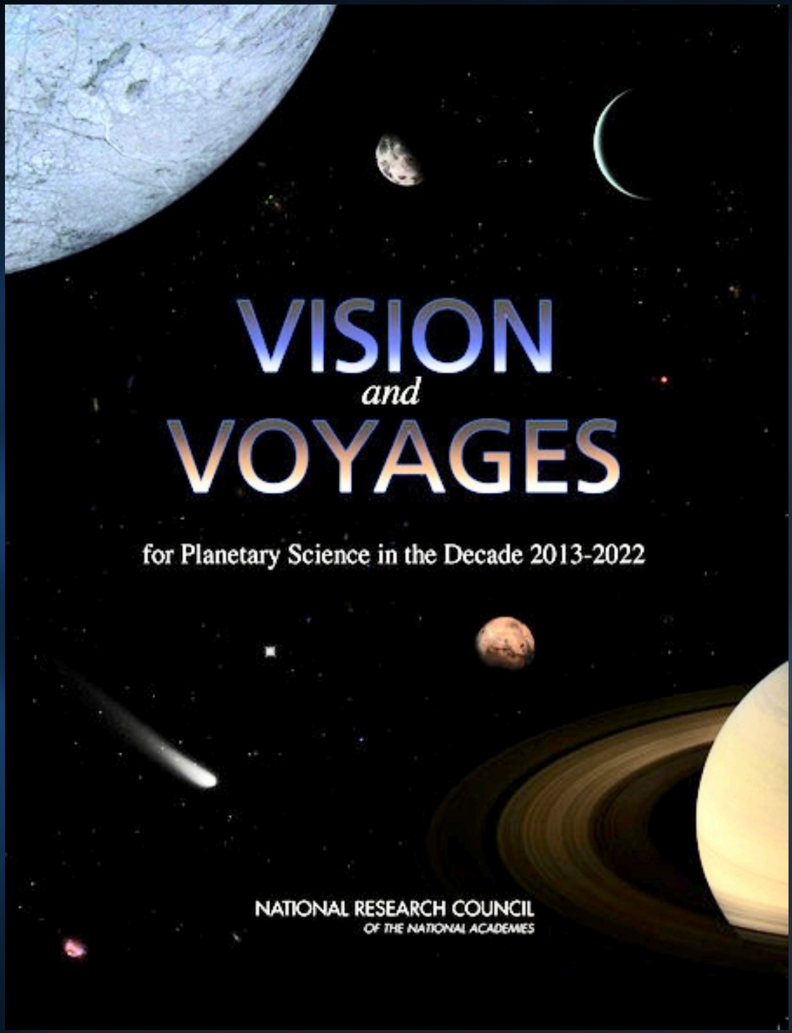


MARS EXPLORATION PROGRAM – DECADAL PRIORITY

- The committee established three high-priority science goals for the exploration of Mars:
  - Determine if life ever arose on Mars
  - Understand the process and history of climate
  - Determine the evolution of the surface and interior

- *"A critical next step …. will be provided through the analysis of carefully selected samples from geologically diverse and well-characterized sites that are returned to Earth for detailed study using a wide diversity of laboratory techniques"*

- *"The highest priority Flagship mission for the decade of 2013-2022 is MAX-C … However, the cost of MAX-C must be constrained in order to maintain programmatic balance."*



DECADAL SURVEY MSR CONCEPTS

Sample Caching Rover

Evolved to become M2020

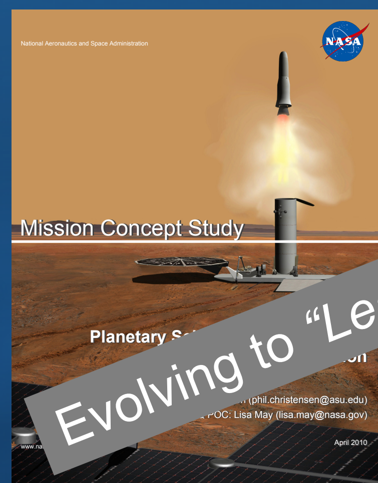
- MSL-heritage Skycrane EDL
- MAX-C Rover (solar powered)
  - Sample Caching System
  - Instrument suite for sample selection/context
  - 2 integrated caches, each w/ 19 sample tubes

<u>Key Technologies</u>

✓ Sample Caching System

✓ Terrain Relative Navigation

Sample Return Lander



Evolving to "Lean Sample Return" concept

- MSL-heritage Skycrane EDL
- Pallet Lander
  - Fetch Rover (157 kg)
  - Mars Ascent Vehicle (2-stage Solid-Solid)
  - 17-cm OS

<u>Key Technologies</u>

- Mars Ascent Vehicle
- Fast Fetch Rover

Sample Return Orbiter

- Round-trip Orbiter (ChemicalPropulsion)
  - MOI, Aerobrake
  - OS Rendezvous & Capture
  - Earth Return
  - Earth Entry Vehicle
- Mars Returned Sample Handling

<u>Key Technologies</u>

- OS Rendezvous and Capture
- Back Planetary Protection
- ➢ Electric Propulsion

STRATEGIC APPROACH FOR MSR IMPLEMENTATION

- *“Lean Sample Return”*
  - Retain flexibility on requirements; cost & risk are part of the essential trade-space
  - Focused scope
  - Capitalize on experience base
  - Limit new development
  - Make early technology investments to mature readiness and minimize cost risks
  - Leverage partnerships
  - Strong programmatic discipline in execution

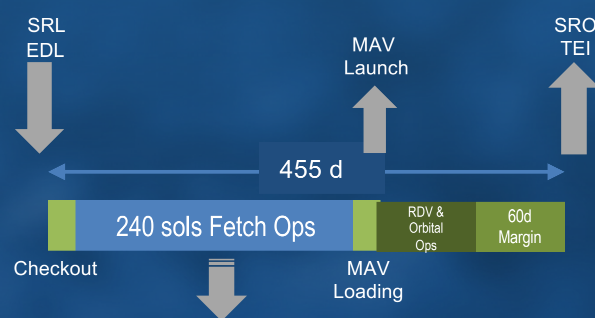
SAMPLE RETURN: KEY REQUIREMENTS

LAND in the right place

Land in small landing error ellipse (≤10 km) to access M2020 sites

COLLECT samples fast

Long traverse with tight timeline



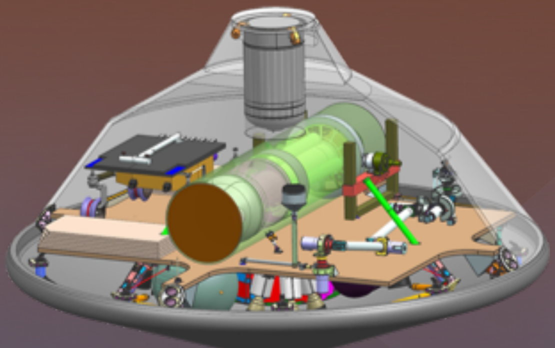
- 130 sols for driving km (rover odometry)
- 20 sols for tube pickup (1 tube/sol)
- 90 sols for faults/anomalies/engineering activities

Get it BACK

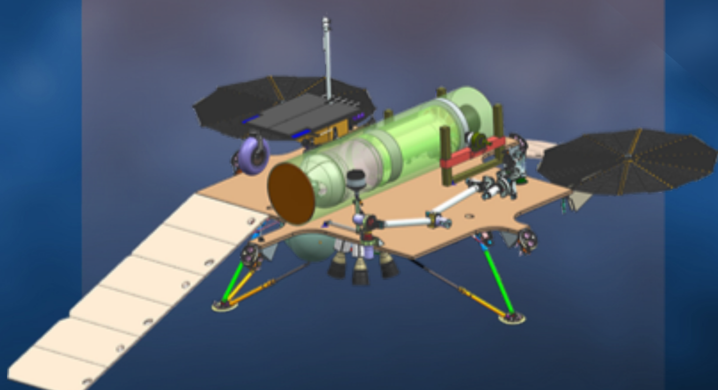
Launch, rendezvous and return

TWO LANDER CONCEPTS

2017 Highly Integrated Concept



***Propulsive Platform Lander (PPL)** Concept Packaged in MSL 4.5m Aeroshell*

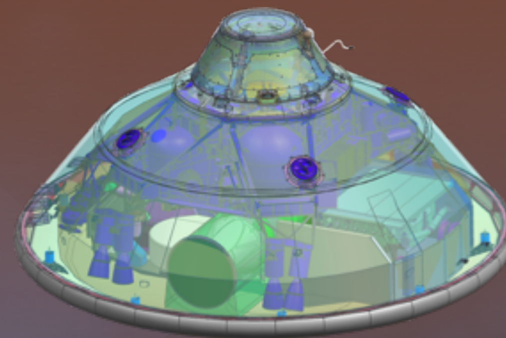


***Propulsive Platform Lander** Concept Deployed*

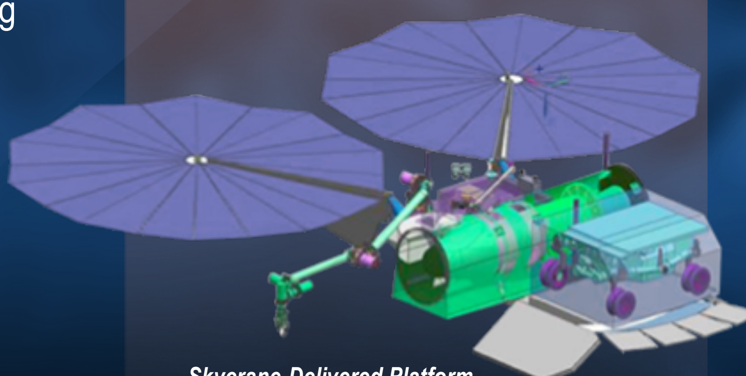
Common Attributes

- Identical cruise and entry architecture
- ~ 10 km landing ellipse
- ~ 900-1000 kg landed useful mass
- Accommodates ~ 600 kg MAV and Fetch Rover

Evolved 2011 Decadal Concept



Skycrane-Delivered Platform Concept Packaged in MSL 4.5m Aeroshell



***Skycrane-Delivered Platform** Concept Deployed*

Two concepts that leverage Mars program legacy system capabilities

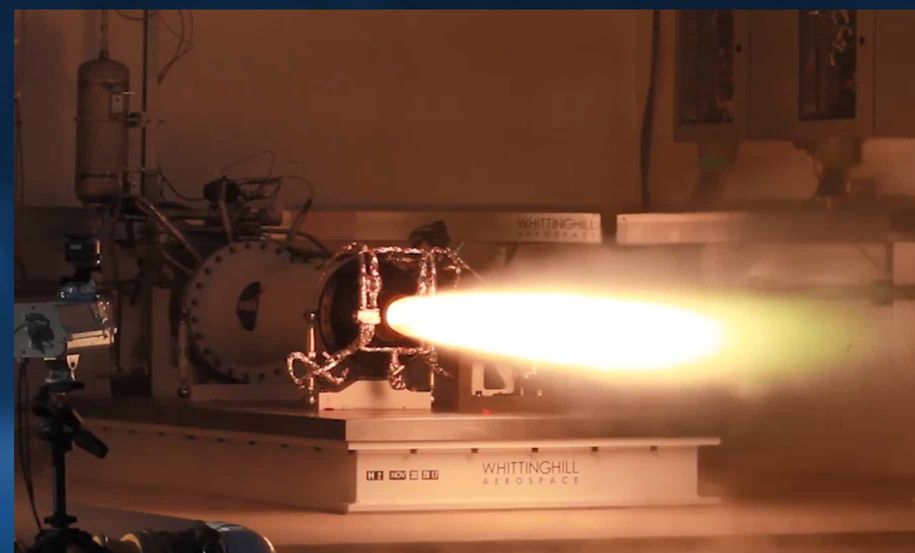
MAV - TECHNOLOGY MATURATION

Objective

- Achieve stable orbit @ 18 deg, 350 km circular
- Minimize thermal survival power
- Constrain mass/volume

Technology Maturation Progress

- Pursuing hybrid propulsion SSTO approach
  - Paraffin based fuel has superior cold temperature properties (-90 C)
  - Inert fuel grain and low temp MON3 oxidizer
- Full scale motor test firings in-work



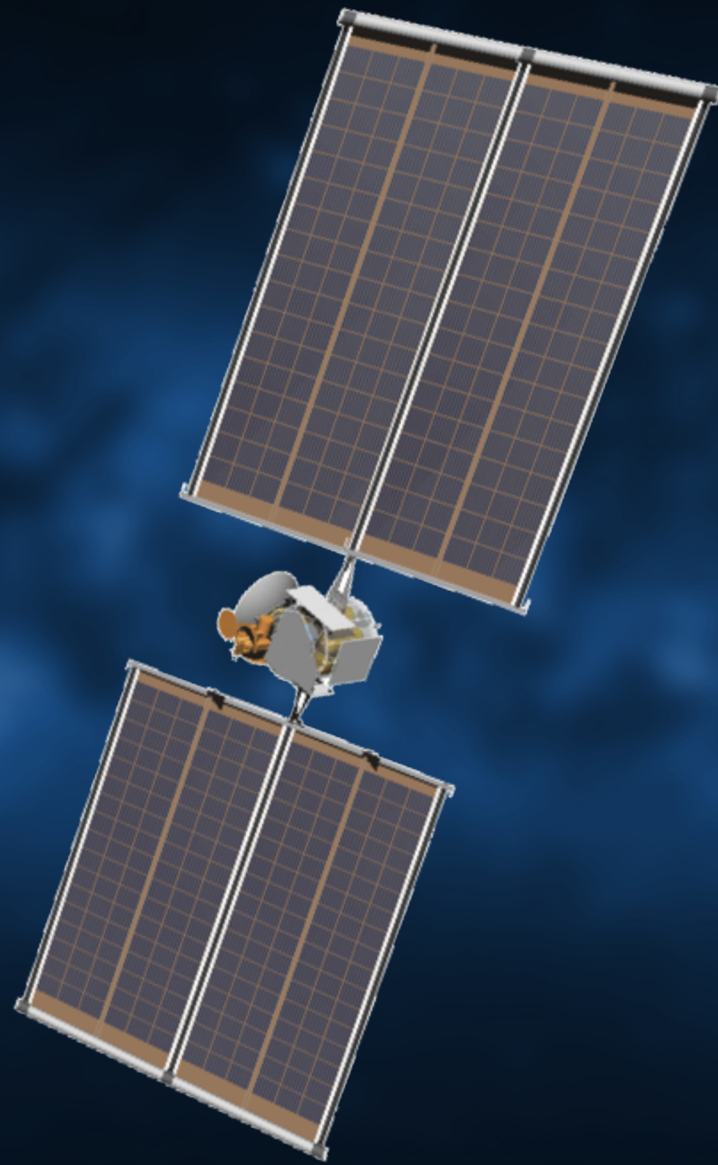
Full-scale hybrid motor test at Whittinghill Aerospace – Nov 2017

Mars Ascent Vehicle (MAV)
~2.4m length/~ 300 kg mass

EARTH RETURN ORBITER CONCEPT

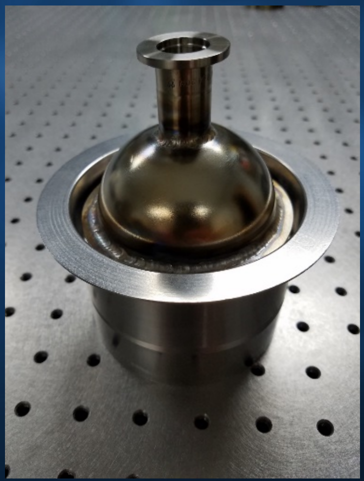
Orbital Rendezvous & Fast Sample Return

- Mars Orbit Sample Rendezvous & Capture
- Bio-Containment and Earth Planetary Protection
- Communication Relay Support for Surface Ops
- Return to Earth, either via
  - Direct return to Earth in EEV
  - Deliver to cis-lunar space for human-assisted return



BIO-CONTAINMENT TECHNOLOGY MATURATION

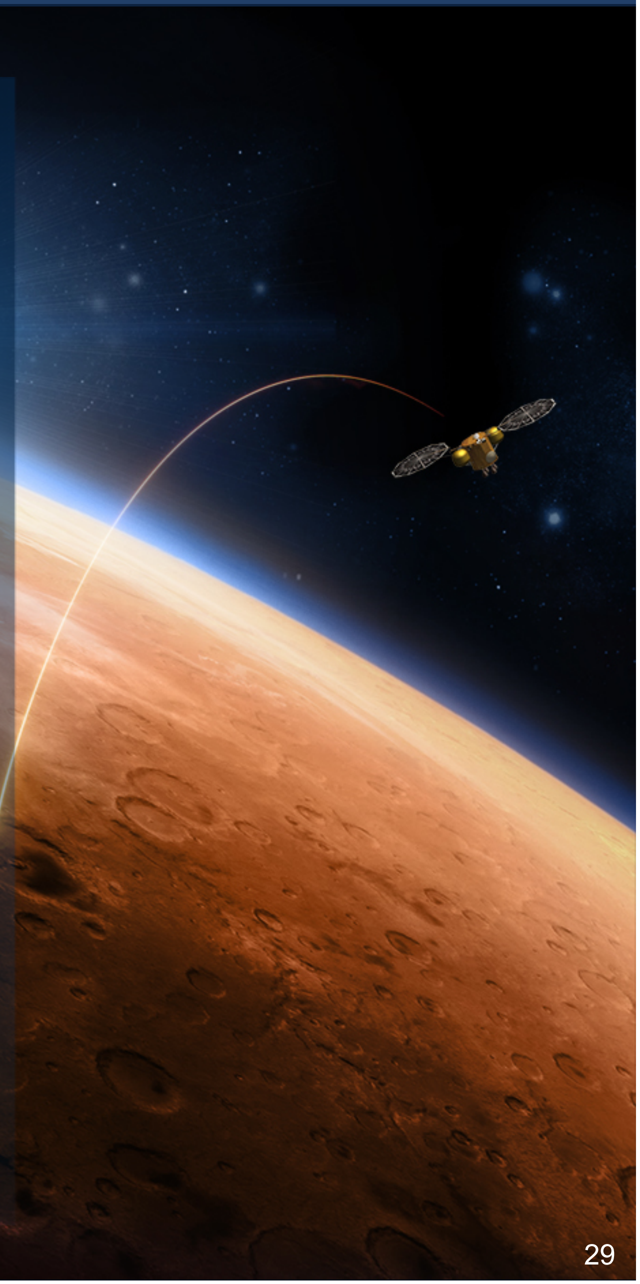
- Simultaneous Sealing and Sterilization via Brazing
- Cone-within-cone design serves both structural and sealing functions
  - Approach has been validated using 4” bench test induction heater
  - Multiple test items successfully brazed
  - Sealed and separated containers were tested with spectrometer/vacuum/Helium

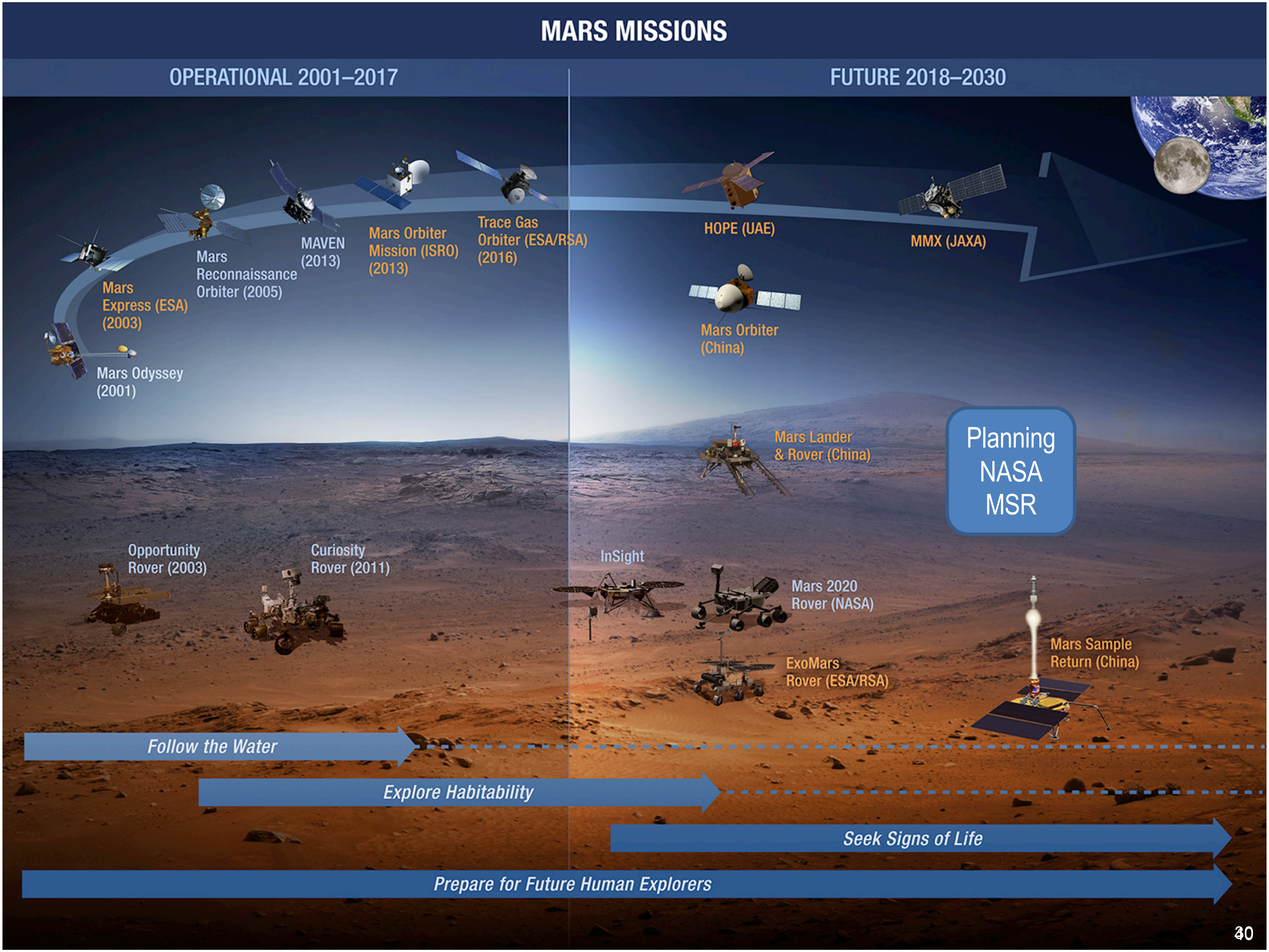


He leak test

PARTNERSHIP OPPORTUNITIES

- **International**
  - Enduring scientific/technical and programmatic interests
  - Multiple space agencies headed to Mars
- **Growing commercial interest in Mars**
  - Potential to leverage commercial offerings of capability
- **Exploration benefits from MSR**
  - Feed-forward into preparation, planning and development
  - First round trip demonstration
  - Samples inform environmental uncertainties [biological, physical, toxicity]
  - Potential opportunity for early leverage of cis-lunar capabilities




MARS MISSIONS
OPERATIONAL 2001–2017
FUTURE 2018–2030
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
HOPE (UAE)
MMX (JAXA)
Mars Orbiter (China)
Mars Lander & Rover (China)
Planning NASA MSR
Opportunity Rover (2003)
Curiosity Rover (2011)
InSight
Mars 2020 Rover (NASA)
ExoMars Rover (ESA/RSA)
Mars Sample Return (China)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

MARS EXPLORATION PROGRAM – SUMMARY

- MEP is a healthy program
  - Current missions still productive
  - Development missions/systems doing well
  - Beginning early-stage work on a potential lower cost MSR mission, long a Decadal priority, leveraging international and commercial partnerships

- Upcoming meetings of interest
  - MEPAG – April 3-5, 2018
  - IMEWG – April 23-24, 2018
  - 2nd International MSR Conference – April 25-27, 2018